FAMILIAR TALKS

ON

ASTRONOMY.

FAMILIAR TALKS

ON

ASTRONOMY

WITH CHAPTERS ON

Geography and Navigation

BY

WILLIAM HARWAR PARKER

AUTHOR OF "RECOLLECTIONS OF A NAVAL OFFICER," ETC.

CHICAGO

A. C. McCLURG AND COMPANY

1890

Copyright
By A. C. McClurg and Co.
A.D. 1889

PREFACE.

THIS little book I have called "Familiar Talks;" it assumes to be nothing more. It embodies the gist of the lectures I have been in the habit of delivering in the class-room, and is written mostly from memory. It is the result of thirty years' study, observation, and meditation.

I do not pretend to introduce anything new; but simply to put some matters in a different and, perhaps, more attractive form. I have contented myself with presenting general facts, and have purposely avoided entering into *minutiæ*. I have, for instance, spoken of the exact dimensions of the earth, though astronomers say we do not know the "exact" dimensions. I have spoken of the earth's rotation as being uniform, when astronomers say it is "suspected" it may not be, etc.

All such questions, as whether we really know the *exact* dimensions of the earth; whether its

diurnal motion is *absolutely* uniform; the *constancy* in position of the earth's axis; the physical problems presented by the sun and moon; the determination of the parallax of the stars, and many similar ones, should be left to the specialists who are spending their lives in the attempt to elucidate them. This book is not written for scientists — who are reckoned by the hundred — but rather for the school-boy and general reader, who are reckoned by the million.

I have used few diagrams, because I believe the student had better *think out* many matters for himself. I have repeated myself frequently and intentionally when I particularly wished to impress a certain point upon the reader, and the quotations are introduced for the same purpose.

The *definitions* are put in the appendix for the student to refer to, though many are embodied in the text. I can see no more reason for putting a collection of definitions in the first chapter of an astronomy, than for making a boy commit to memory all the words of a Latin dictionary before he commences to translate *Historia Sacra.*

In the last chapter will be found some general remarks on Navigation. The theory by

which a ship's position at sea is found is so simple as to be readily comprehended by the general reader, and should unquestionably be taught to the school-boy.

It is usual for writers on astronomy to give a list of the books consulted by them. While writing these *talks* I have had lying upon my desk Lockyer's Elementary Astronomy, and Professor White's Elements of Theoretical and Descriptive Astronomy. But I have read in the last thirty years a great many books on this subject. I cannot remember the names of all of them. It is not necessary; for, as I have said, I do not pretend to give the reader any new facts. Indeed, I confess — to use the words of Sir Henry Wotton — "I am but a gatherer and disposer of other men's stuff."

I desire to express my thanks to Rear Admiral S. R. Franklin, Superintendent of the Naval Observatory, and to Professor A. Hall, of the Observatory, for their kindness in reading my manuscript; also, to Professor Keeler, of the Lick Observatory. To the last two I am indebted for valuable hints.

FREDERICKSBURG, VA.,
March, 1889.

CONTENTS.

TALK THE FIRST.

PAGE

The necessity of thought and meditation. Astronomy defined. Its language. The Solar system. The ancient astronomers, and what they observed. Time and the Calendar. Progress of the science of astronomy. Pythagoras, Aristarchus, Hipparchus, Ptolemy. The Copernican Theory. Galileo, Kepler, and Newton. The Earth. Its shape. Its motions. Its size, and how determined. 15

TALK THE SECOND.

The Change of Seasons. The Ecliptic. The Obliquity of the Ecliptic. Declination. Arctic and Antarctic Circles. Tropics of Cancer and Capricorn. Solstices. Equinoxes. Apparent motion of the Sun. Celestial Poles. Celestial Equator. Sun's Distance from the Earth variable. Perihelion and Aphelion. Angular, or Apparent Diameter. The Obliquity of the Ecliptic wisely ordained. Durations of the Different Seasons. 39

TALK THE THIRD.

Long Days and Short Nights, and *vice versa*. Solstices. Equinoxes. Twilight. The Midnight Sun. Arctic Voyagers. Appearance of the

PAGE

Heavens to an observer at the Poles; and at the Equator. Velocity of the Earth in its orbit, and upon its axis. 49

TALK THE FOURTH.

The Moon. Its shape. Its size. Its Distance from the Earth. Its motions. The Moon's Phases. Rule for finding the Moon's age. "Earth-shine," or Secondary Light. The Moon's side. Real and Synodic Periods. Perigee and Apogee. Librations. 65

TALK THE FIFTH.

The Moon's Angular, or Apparent Diameter. Its Distance from the Earth variable. Parallax. Horizontal Parallax. How it is found. Method of Computing the Moon's Distance from the Earth, and its Diameter and Volume. Light shed by the Moon. Nodes. Physical Constitution of the Moon. Lunar Cycle. Influences. Tides. Attraction of Gravitation at Surface. . 78

TALK THE SIXTH.

The Sun. Its Shape. Size. Motion. Distance. Relative Distances of the Planets from the Sun. Transits of Venus. Sun's Parallax. How determined. Method of finding the Sun's Distance, Diameter, and Volume. Disk. Photosphere. Point at which Sun rises. 93

TALK THE SEVENTH.

Eclipses. Occultations. A Solar Eclipse. Total, Annular, and Partial, Eclipses. Digits. Lunar Eclipse. Inclination of Moon's Orbit to Plane

PAGE

of the Ecliptic. Number of Eclipses in a Year. Cycle of Eclipses. Sun's Influences. Its Light and Heat. 105

TALK THE EIGHTH.

Recapitulation. The Planets. Those known to the Ancients. Discovery of Uranus and Neptune. Inferior and Superior Planets. Satellites. Discovery of the Satellites of Jupiter and Mars. Speculations of Bishop Wilkins, and others, concerning the Moon. The Elephant in the Moon. Mercury; its Size, Distance from Sun, and Motions. Inferior and Superior Conjunctions. Quadratures. Phases. Transits. Venus; its size, distance from Sun, and motions. Phases. Transits. Mars; its size, distance from Sun, and motions. Opposition and Conjunction. Jupiter. Saturn. Uranus. Neptune. Bode's Law. The Satellites of Jupiter. 112

TALK THE NINTH.

Recapitulation. Discovery of the Velocity of Light. The Asteroids. Are the Planets Inhabited? Change of Seasons at Jupiter and Mercury. Aberration of Light. Kepler's Laws. Determination of the Density and Mass of the Earth. Density of the Planets. The Planets' Motions in their Orbits. 134

TALK THE TENTH.

The Stars, their Number, Magnitude, Parallax, Distance. Colored Stars. The Constellations. Geography of the Heavens. Use of Globes. The Zodiacal Constellations. Classification of

PAGE

the Stars. The Milky Way. Double Stars. Variable Stars. Star-Clusters. Nebulæ. The Magellanic Clouds. Meteors. Meteorites. Star Showers. Comets. Star-Dials. Precession and Nutation. 149

TALK THE ELEVENTH.

Time. Its Measurement. Standard of Time. Apparent Solar Day. Sidereal Day. Mean Solar Day. Equation of Time. Mean Time and Apparent Time. The Civil Day. The Astronomical Day. Lunar Day. Sidereal Time. Clepsydræ. Sun-Dials. Clocks and Chronometers. The Week. The Month. Lunar Month. Sidereal Month. Calendar Month. Tropical Month. Anomalistic Month. Nodical Month. The Year. Sidereal Year. Tropical Year. Anomalistic Year. Absolute and Relative Time. Local Time. Standard Time. 168

TALK THE TWELFTH.

International Conference, held at Washington, for the adoption of a Single Prime Meridian, and a Universal Hour, October, 1884. Explanation of the method by which Navigators adjust their time when circumnavigating the globe. . . . 187

TALK THE THIRTEENTH.

Nautical Astronomy. Astronomical Instruments. The Transit Instrument. The Meridian Circle. The Prime Vertical. The Mural Circle. The Equatorial Instrument. The Nautical Almanac. The Early Navigators. The Mariner's Compass. Voyage of Columbus. The Trade Winds. The Sargasso Sea. Variation of the Compass. . . 198

TALK THE FOURTEENTH.

PAGE

The Sextant. Index Correction. Semi-Diameter. Dip of the Horizon. Refraction. Parallax. Departure. Course and Distance. Log Book. Log and Line. Difference of Latitude, and Difference of Longitude. Method of finding the Latitude by the Sun's meridian altitude. The Chronometer. Method of finding the Longitude by Chronometer. The Lunar Observation. Charts. Azimuth and Amplitude. Calculation of the Time of Sunrise and Sunset. The Artificial Horizon. Error and Rate of a Chronometer. Distance at which an object is visible at sea. High Water. The Merchant Marine. 217

APPENDIX.

DEFINITIONS 247

INDEX. 259

FAMILIAR TALKS

ON

ASTRONOMY, GEOGRAPHY, AND NAVIGATION.

TALK THE FIRST.

The necessity of thought and meditation. Astronomy defined. Its language. The Solar system. The ancient astronomers, and what they observed. Time and the Calendar. Progress of the Science of Astronomy. Pythagoras, Aristarchus, Hipparchus, Ptolemy. The Copernican Theory. Galileo, Kepler, and Newton. The Earth. Its shape. Its motions. Its size, and how determined.

IT is my design to tell you in these talks something about the Earth and heavenly bodies. I do not propose to write a *complete* treatise on astronomy; but I hope to give you an idea, at least, not only of the forms, dimensions, distances, motions, etc., of the Earth, Sun, Moon, planets, and stars, but also of the methods by which their orbits and sizes are calculated. While I do not expect to tell you anything new concerning these bodies, I do intend to try to put some subjects before you in a different

light than that given in our ordinary text-books, and I shall endeavor to convey to you as much information on this most interesting science as will enable you to understand what is usually called Descriptive and Practical Astronomy. Those desiring to pay especial attention to the subject will, of course, proceed to more scientific works; and I will be glad to think that this little book has led them to give the subject more time and attention.

There is probably no science that requires more abstract thought than astronomy, and if I succeed in impressing upon you the necessity of *thinking*, I shall not have talked to you in vain.

A recent writer commenting upon the serious air of the people generally, — an air of unhappiness in fact, — says it is occasioned by the too constant reading of many books. I am not at all sure but that he is right; perhaps we should think more and read less. Carlyle says: —

"A very small lot of books will serve to nourish a man's mind, if he handle them well; and I have known innumerable people whose minds had gone all to ruin by reading carelessly too many books. . . . The wisest men I have known in this world were by no means great readers — good readers, I should rather say, of a few books that were wise. . . . A man gathers wisdom only from his own sincere exertions and reflections."

When we read the lives of Thomas Jefferson, James Madison, John Adams, and others of their time, we are struck with the great originality of thought of these men. They certainly had but few books; but the contents of these books they digested well. They spent hours in their libraries daily, — not always reading, but thinking. Rousseau says: "Naturally, man thinks but little. Thinking is an art which he learns as any other, though with more difficulty. I only know, in the two sexes, two classes really distinct: those who think, and those who do not think; and this difference comes almost entirely from education." Pascal says, "All our dignity consists in thought;" and Gibbon says, "The use of our reading is to aid us in thinking."

I will not say that this habit of thinking is a lost art; but I do very much fear that in our schools the memory is often cultivated at the expense of the understanding, and that the scholar is not fully made to comprehend that one of the definitions of "study," is meditation. The ancient philosophers, of whom our books tell us so much, were, after all, I suspect, simply "thinking" men.

The word "astronomy" comes from the Greek, and means literally "the law of the stars." We define it, however, as "the science which treats

of the heavenly bodies," which you observe embraces more; because all the heavenly bodies are not stars, as we shall soon see.

It is divided into Theoretical, Practical, Nautical, and Descriptive Astronomy. Theoretical Astronomy explains the rules for calculating the masses, motions, and positions of the heavenly bodies, and it requires a good mathematician to understand and work them. Practical Astronomy applies to the use of instruments. Nautical Astronomy is that branch of the science which teaches the navigator to find the position of a ship on the ocean. Descriptive Astronomy comprehends a general description of the heavenly bodies; of their forms, magnitudes, distances, motions; of their appearance and structure; of, in short, everything relating to these bodies which comes from observation or calculation.

Our talks will be on Descriptive and Nautical Astronomy, with an occasional glance at Theoretical and Practical Astronomy.

Now I suppose you to be acquainted with the *terminology*, or nomenclature, of this science of astronomy. All sciences have a language of their own. You know what an algebraic formula is. It is a general rule expressed in algebraic language; and when we wish to express it as a theorem, we first translate it into ordinary language. For example, in the problem of the

couriers, where we desire to know how many hours will elapse before the rear courier will overtake the one in advance, if we suppose x to represent this time, a to represent their distance apart, and m and n their respective rates per hour, we find —

$$x = \frac{a}{m - n};$$

which is an algebraic formula, and translated means that the time required will be equal to the distance of the two couriers apart, divided by the difference between their rates of travel. And this theorem applies to every possible similar problem.

Well, then, as I say, I suppose you to know the language of astronomy, and if you do not you must, where I use a word you do not understand, look it up in the Appendix, precisely as you do when you look up the definition of a word in your Latin or French dictionaries.

I suppose, too, that you are all tolerably familiar with what is called the Solar System, — that is, *our* System. The Sun being supposed to be the centre, all the planets — Mercury, Venus, the Earth, Mars, the asteroids, Jupiter, Saturn, Uranus, and Neptune — in succession, revolve about it in a direction from west to east. They all rotate upon their axes in the same direction, and those of them that have satellites carry

them with them in their revolutions about the sun.

This is called the Copernican Theory, and is the one universally recognized as the correct one.

You must bear in mind that the stars are suns; they shine by their own light, and probably each one is surrounded by planets, and is the centre of a system, just as our sun is. But this we need not dwell upon here.

Let us see how this science of astronomy began. Who were the first observers of the heavens? Shepherds and sailors, of course. Their occupations kept them up at night, and they naturally observed the heavenly bodies. What do any of us in the towns and cities see of the heavens, unless we go on the tops of our houses, which I am sure we none of us do. How different the case with the shepherds on the great Eastern plains, or sailors on the broad ocean! They are not only up much at night, but they have a clear view of the heavens. Moreover, in early times they judged of the hour by the positions of the stars and directed the course of their ship at night by them. It may be that the reason why the Arabians and other Eastern nations knew so much about the stars was owing to their custom of sitting on the tops of their houses at night. Having an unobstructed view of the sky they were per-

haps led to examine into the motions of the heavenly bodies.

The shepherds,[1] then, were the first astronomers, or perhaps I had better say, the first observers of the heavenly bodies.

What did they first notice? Naturally, the sun. They saw that it was a round, luminous body; and that it rose in the east and set in the west.

Next they observed the moon. But here was a change. While the sun always presented the same appearance, the moon changed from a crescent to a circle, and about every thirty days it disappeared altogether for a day or two. Moreover, its time of rising changed from night to night.

Here was food for thought. It was certainly not a self-luminous body, otherwise it would not change its apparent shape; and the change in the hour of rising indicated a different motion from that of the sun.

Next our early astronomers turned their attention to the stars. Here they saw innumerable luminous heavenly bodies rising at all points of the compass in the east, between north and south, and setting in the west at all points between north and south. Some of these stars were always visible at night and evidently did not set at all. These stars are now called

[1] The shepherd Endymion, according to Pliny, first observed the course of the moon, and its changes.

circumpolar stars. The farther north or south the observer, the more stars there are that do not rise or set. We will speak more particularly of them farther on.

They noticed also that the stars preserved their relative positions towards each other; and that they rose at about the same hour every night. A closer and longer observation, however, showed them that they really rose a little earlier every night, and that, as a consequence, the aspect of the heavens in the course of a year was changed. At any hour, say midnight, after an interval of six months, an entirely different set of stars was above the horizon, — save only the circumpolar stars which were always above the horizon.

But what must have excited the wonder of these observers was the fact that although most of the stars preserved their relative positions, as I have said, there were some, and very bright ones too, which wandered among the others. They sometimes appeared in one constellation and sometimes in another. They may have noticed, too, that these bodies did not "twinkle." They called them *planets*, from the Greek word signifying to wander.

Let us now look back and see what our shepherds have noticed: first, the sun; secondly, the moon and its phases; thirdly, the stars and constellations (which are merely groups of

stars); and fourthly, the planets, — all with the naked eye.

Comets, too, they must have occasionally seen, moving with great velocity among the stars and with long streamers of light behind them; also meteors, those bodies we call "shooting stars."

They must have observed, also, that the sun never rose at exactly the same point in the east; and I may perhaps astonish you when I tell you that the sun never does rise due east, and set due west, but twice in the year, — *i. e.* at the two equinoxes. This I will explain when I come to talk about that luminary.

The natural standard of time is one revolution of the earth upon its axis. This the early nations called day and night. The next step in their reckoning of time was by the moon. You see how naturally this came about. They reckoned from one new moon to the next. This is what we call a lunar month. You know that the American Indians express an interval of time as so many "moons," they say, such an event occurred a certain number of "moons" ago.

The next step was to find the length of the year. This the ancients soon discovered. It is said that Thales, one of the seven wise men of Greece, first recommended the division of the year into three hundred and sixty-five days. This was about six hundred years before Christ

was born. It was not so difficult to discover the length of a year (or the time it takes the earth to make one revolution about the sun) as you may imagine it to be.

You know the length of the shadow of an object, cast by the sun at mid-day is constantly changing. The shadow (in the northern hemisphere) cast by any steeple, at noon, is shortest on the 21st of June (the summer solstice), and longest on the 21st of December (the winter solstice). You have only to measure these shadows, daily, and from the greatest to the greatest again, or from the least to the least again, is about three hundred and sixty-five days. This was the way Thales discovered the length of a year, and it is a close approximation. By observing the intermediate shadows he determined the equinoxes.

Some time before Cæsar it was found that the length of the year was not exactly three hundred and sixty-five days, but was about 365¼ days. You readily see that if we reckon the length of the year other than it really is, the Calendar, as it is called, must get into a state of confusion; our January might eventually come into the middle of summer, and our June into the middle of winter.

Well, in the time of Julius Cæsar, about fifty years before Christ, the calendar had fallen into such confusion that he called in the aid of the

Egyptian astronomer Sosigenes, to reform it. He assumed the length of the year to be just $365\frac{1}{4}$ days, and by making every fourth year to consist of three hundred and sixty-six days, that is, by the introduction of the leap-year, it seemed as though the difficulty was solved. It would have been if the length of the year *was* exactly $365\frac{1}{4}$ days; the addition of one day every four years (and you know it had to be changed a day or twenty-four hours at a time) would have kept the calendar perfecty correct.

The Arabians made great progress in mathematics and astronomy, and in A. D. 879 Albategnuis calculated the length of the year to be three hundred and sixty-five days, five hours, forty-six minutes, twenty-four seconds; which is very nearly correct. The exact length is three hundred and sixty-five days, five hours forty-eight minutes, forty-six seconds; so you see that the Julian calendar was itself getting into confusion, — very slowly it is true; but in 1582 it was found to be in error about ten days.[1] Pope Gregory XIII. had it corrected

[1] By the Gregorian rule every year exactly divisible by 4 is a leap-year, excepting the closing years of the centuries, which must be divisible by 400 to be taken as leap-years, — thus 1900 is not a leap-year, 2000 is a leap-year, 2100 is not and so on. The year 1900 is the last year of the nineteenth century; 2000 the last year of the twentieth century and so on.

The first day of January, 1901, begins the twentieth century. The "London Standard" gives the following explanation why

so carefully that it will not be one day in error in nearly four thousand years. The Gregorian calendar was adopted in England in 1752; and this will explain to you why in some old books you find two dates given, — Old Style and New Style. Russia has not yet adapted the Gregorian calendar, and the Russian reckoning is now twelve days behind ours, — but all the other European nations use it, as do all the American nations.

The Chaldeans, Egyptians, and probably, the Chinese were the first to make any material

the year 1900 will not be counted among leap-years. "The year is three hundred and sixty-five days, five hours, and forty-nine minutes long; eleven minutes are taken every year to make the year 365¼ days long, and every fourth year we have an extra day. This was Julius Cæsar's arrangement. Where do these eleven minutes come from? They come from the future, and are paid by omitting leap-year every hundred years. But if leap-year is omitted regularly every hundredth year in the course of four hundred years it is found that the eleven minutes taken each year will not only have been paid back, but that a whole day will have been given up. So Pope Gregory XIII. who improved on Cæsar's calendar in 1582, decreed that every centurial year divisible by four should be a leap-year after all. So we borrow eleven minutes each year, more than paying our borrowings back by omitting three leap-years in three centurial years, and square matters by having a leap-year in the fourth centurial year. Pope Gregory's arrangement is so exact, and the borrowing and paying back balance so closely, that we borrow more than we pay back to the extent of only one day in three thousand eight hundred and sixty-six years."

The Christian era is said to have been first proposed in the year 527 A. D. (Chambers's Enc.)

progress in astronomy. Then came the Greeks and Arabians.

Pythagoras, a Greek philosopher, who lived about five hundred years before Christ, asserted that the earth was not fixed; but he did not know that it revolved about the sun. It was Aristarchus, another Greek, who flourished about the middle of the third century before Christ, who discovered that the earth revolved about the sun. It was known as the Pythagorean system, but was not generally accepted as true.

The most famous astronomer before the Christian era was Hipparchus, who lived about 160 B. C. He observed the "precession of the equinoxes," catalogued one thousand and eighty stars, and calculated eclipses. He determined the periods of the planets with a good deal of accuracy. His periods of Mercury, Venus, and Mars are in error only a few minutes.

About the year 70, or some say 140, after Christ, Ptolemy, a native of Egypt, an astronomer and geographer of Alexandria, published his work, — called by the Arabs the "Almagest." He taught that the earth was the centre of our system and that the sun, moon, planets, and stars revolved about it. This was known as the Ptolemaic system and was accepted as the correct one. It was in use about fourteen hundred years.

It was, however, reserved for Copernicus, a Pole by birth and a priest by profession, to establish the system now accepted as the true one. Copernicus was at one time a professor of mathematics at Rome, and afterwards a canon of Frauenberg in Prussia. He conceived the theory of the earth's motion about the sun, A. D. 1520, but did not dare to publish it until the year 1543. This is known as the *Copernican Theory*. Its three fundamental points are: (1) that the earth is round; (2) that it turns upon its axis from west to east; (3) that the earth and other planets revolve about the sun.

After Copernicus came Galileo,[1] who first used the telescope, in 1610; Kepler, who at the same time worked out his three grand laws about the movements of the planets; and Newton, who in 1687 published his great work on Universal Gravitation. From this time the science of astronomy has made wonderful progress; and, what with the improvements of telescopes and other astronomical instruments, and the great interest exhibited by *savans* in everything relating to it, the student finds it difficult to keep

[1] The practical discovery was about 1608. (Enc. Brit.) And yet Rogers, in his "Voyage of Columbus," (1492) says:

> "What long-drawn tube transports the gazer home,
> Kindling with stars at noon the ethereal dome?"

And again —

> "But soon the *telescope* attracts her view."

up with the discoveries and various theories advanced.

Since it was only in 1543 that Copernicus promulgated his system, I call your attention to the fact that Columbus (who in 1492 discovered America) knew nothing about it, of course. He probably believed in the Ptolemean Theory. He believed the earth to be round; otherwise he would not have expected to reach China and Japan by sailing west. He greatly under-estimated the dimensions of the earth; and we shall see farther on that Sir Isaac Newton, in 1666, had to suspend his calculations for some sixteen years, to wait for a more accurate measurement of it.

THE EARTH.

The Earth being the planet on which we live, is, of course, the one we are most interested in. Let us see what we know about it.

It is round. It is not a perfect sphere; but its exact shape is what mathematicians call an oblate spheroid, — that is, its polar diameter is less than the equatorial diameter. We readily see how it assumed this shape. As in the beginning it was a molten, yielding mass, when it was set in motion on its axis it *bulged* at the equator; precisely as a ball of soft putty would do if it should be spun rapidly round its axis.

How did the ancients know that the earth is round? I can give you three reasons: (1) The horizon is always a circle; (2) The shadow of the earth thrown on the moon in a lunar eclipse is circular; (3) When vessels are observed coming in from sea their upper sails are first seen, and their hulls last.

We know a better reason than any of these: *ships sail around it.* Who first sailed around the world? Magellan, a Portuguese in the service of Spain, in 1519. He was killed at the Philippine Islands; but his ship, under Sebastian del Cano, completed the voyage. So you see that Columbus, although he believed the earth to be round, did not *know* it as we do, for up to his time it had not been circumnavigated.

The earth turns upon its axis, from west to east, once in 23 hrs. 56 min. 4 seconds. We see this by the stars, as we cannot suppose them to be revolving about the earth. Moreover, this has been experimentally illustrated by the French philosopher, Foucault, in two ways, — by means of a pendulum, and by means of an instrument called the gyroscope.

The pendulum experiment is based upon the fact that if a heavy weight is suspended by a fine cord, and then swung, it will continue to swing *in the same plane* or *same direction*, even

though the point of suspension be moved. Could this experiment be made at the north pole, the earth would revolve under the pendulum once in 23 hrs. 56 min. 4 seconds.

Foucault's pendulum was suspended from the dome of the Pantheon, in Paris, and a fine point at the bottom of the weight was made to leave a mark in sand at each swing. The experiment was also made at Bunker Hill monument some thirty-five years ago, if my memory is not at fault. You observe that the farther north it is tried the more satisfactory the result. At the poles the sandy dial would be carried round, under the point of the pendulum, once in about 24 hours. At the equator there would be no result.

The experiment with the gyroscope is rather difficult to explain, but the result is the same; the earth is shown to turn upon its axis from west to east.

The earth is a non-luminous body. This needs no proof. To "the man in the moon" the earth presents the same appearance that the moon does to us. It shines by the reflected light of the sun, and exhibits phases; that is, it appears crescent-shaped, gibbous, and full. But it never sets,[1] and appears four times as

[1] It never sets because the moon always presents the same side to us, as we shall see farther on. To an inhabitant of this side of the moon, the earth, of course, would be always visible.

large as the moon does to us. What a magnificent spectacle!

The polar diameter of the earth is about 7900 miles, and the equatorial diameter 7926 miles. How did astronomers measure these diameters? They cannot be measured directly, as you know, but if we can discover the circumference of a circle we can calculate the diameter. How did astronomers measure the circumference of the earth, when no traveller has been within 400 miles of the north pole, and not nearly so close to the south pole? We are told that Eratosthenes, B. C. 276, was the first to attempt to measure the size of the earth.[1] He was not so much an astronomer as a geographer.

Eratosthenes calculated that the distance between Syene and Alexandria (Egypt) was one-fiftieth of the whole circumference of the earth. He found this out by an attempt to discover the angular difference of latitude between the two places. He then measured the distance

[1] The Encyclopædia Britannica says on this point: "It had been ascertained by the surveyors of Alexander and the Ptolemies that the itinerary distance between Syene and Alexandria was 5000 *stadia*. Hence, 5000 × 50 = 250,000 = circumference of the earth. Unfortunately, on account of the uncertainty respecting the length of the *stadium* here employed, we possess no means of estimating the degree of approximation afforded by this rude though ingenious attempt."

Webster says the *stadium* = 606 ft. 9 in. Assuming this to be correct, and taking the geographical mile to be 6016 feet, we find the circumference to be 24,924 miles.

between them, and found it to be 625 miles.[1] 625 multiplied by 50 gives 31,250 miles for the circumference of the earth, which is as nearly correct as could be expected with the means at his command. He measured the difference of latitude by means of what the Greeks called a *gnomon*, an upright pillar which was used by them to measure the sun's altitude by means of its shadow. He made many errors in his observations. He took Syene, or Assouan, as it is now called, to be in lat. 23° 30′ N., because he observed that the *gnomon* cast no shadow there at the time of the summer solstice, when it is directly overhead to persons in that latitude. His observation was erroneous, for Assouan is in latitude about 24° north. Moreover, he supposed Assouan and Alexandria to be on the same meridian, which is far from being the case; and lastly, he largely over-estimated the distance between them.

It is on the same principle that astronomers have since arrived at the exact dimensions of the earth. They have found the length of one degree of latitude to be sixty geographical miles; 60 multiplied by 360 equals 21,600 miles, which is about equal to 25,000 statute miles; and this in round numbers is the distance around the earth at the equator. Of course it is less, in an east and west direction, as we approach the poles. Knowing the cir-

[1] This statement is considered by most astronomers as very doubtful.

cumference of a circle we have only to divide it by 3.1416 to find its diameter.

Now you are not to suppose that it was so easy to arrive at the length of one degree of latitude. The greatest mathematicians of the world have been employed in this work, — *and you will recognize the importance of finding the dimensions of the earth in the most exact manner when I tell you that the distances and magnitudes of all the other heavenly bodies depend upon it.* Nor must you imagine that a distance of sixty miles is actually measured on the surface of the earth with a line or measuring-rod. A base-line of, say, ten miles is measured, and then by a system of triangulation the distance between the extreme points is calculated.

The measurement of the base-line alone is the labor of months. The ground has to be selected, and instruments have been invented to measure it with the utmost nicety. The Reports of the United States Coast Survey contain interesting information on this point.

In the diagram (Fig. 1), suppose we wish to find the distance between the points A and B. We measure the distance B N; this is our base-line. We then place theodolites at B and N, select some point as M, and measure the angles M B N, and B N M. Then in the triangle B M N, knowing a side and the angles, we calculate the length of the side B M. We now remove the

theodolite from N to M, select some point, as L, and measure the angles L B M and B M L and calculate the sides L B and L M. Remove the theodolite from B to L, select some point, as K, and measure the angles K L M and L M K, and calculate the side K L. Remove the theodolite from M to K, select some point, H, measure the angles H L K and H K L, and calculate the sides H L and H K. Proceed in this manner until A is reached, and the sum of the sides B L, L H, H F, F D, and D A, will be the distance between the points A and B required.

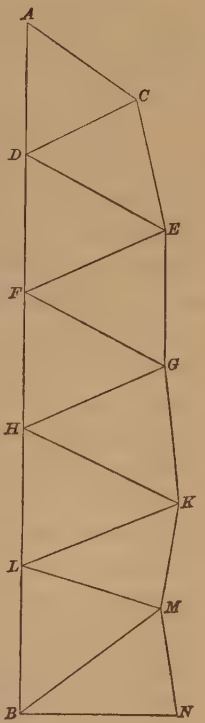

FIG. 1.

The points L, H, F, D, need not necessarily be on the meridian line A B; the diagram is drawn simply to illustrate the method. I cannot enter into the *minutiæ* of the work, as it would require a small volume in itself.

One thing you see; and that is, if we actually measure the last distance A D, and compare it with the calculated distance, it is a test of the

correctness of the triangulation. This is called a verification base.

When Newton first attempted to work out the Law of Universal Gravitation he found his calculations came out wrong. This was in consequence of an error in determining the size of the earth. Not that the error had been made by Newton himself, — he never attempted to measure it, — but he took the figures which were accepted as true at the time. Sixteen years after (in 1682), a French astronomer named Picard measured an arc of the meridian, and Newton adopting his figures discovered the law. This patience on the part of Sir Isaac in laying aside his computations for so many years, and waiting for further information, is even greater than that he exhibited when his dog Diamond destroyed his notes on Chemistry.

Some time after this, Cassini asserted that the degrees of *longitude* varied in length[1] and that the earth was a prolate, and not an oblate spheroid; that is, that its polar diameter was greater than its equatorial diameter. To settle the controversy, France and Spain, in 1735, sent a commission to Peru to make a new measurement; and a party was sent to Lapland at the same time to measure an arc in that latitude. The principal French and Spanish mathematicians were La Condamine and

[1] Meaning, of course, on the same parallel of latitude.

d'Ulloa. Maupertius and Celsius were of the northern party. The arc measured in Peru was in mean latitude 1° 31′ S.; and the one in Lapland in about 66° N. The length of the degree in Peru was found to be 362,790 feet; while the length of the degree in Lapland was 365,744 feet.

Since that time measurements of an arc of the meridian have been made in Sweden, Russia, Prussia, Hanover, Denmark, England, France, Italy, India, and the United States. The least arc measured was 57′, and the greatest 15° 57′. All done by triangulation, as I have said. From these measurements the length of one degree in different latitudes has been found.

The measurement of the arc in the United States was done in 1764 by Mason and Dixon, the same surveyors who ran the line to determine the boundary line between Pennsylvania and Maryland. You have all heard of "Mason and Dixon's line."

The length of one degree of latitude in Lapland is 2,954 feet more than the length of one degree near the equator, you observe. Why is this? If the earth were a perfect sphere, the length of one degree would be the same in all latitudes; and the very fact that the degrees are longer as we approach the poles proves that the earth is flattened at the poles, and hence is an oblate spheroid. Sir Isaac Newton deduced this

from his law of gravitation before any measurements had been made to investigate it.

Let us now look back and see what we have discussed in this *talk*.

1. The necessity of thought and meditation.
2. The definition of astronomy, and its language.
3. What the earliest astronomers must have first observed.
4. Time, and the Calendar.
5. Progress of the Science of Astronomy.
6. The Earth, — its motions, its shape and size, and how determined.

I hope that I have not made this *talk* so long as to tire you; but I hope still more that I have made plain what I have attempted to explain, and that I have conveyed no false ideas; for, as Pope says, —

> "Of the two, less dangerous is the offence,
> To tire our patience, than mislead our sense."

TALK THE SECOND.

The Change of Seasons. The Ecliptic. The Obliquity of the Ecliptic Declination. Arctic and Antarctic Circles. Tropics of Cancer and Capricorn. Solstices. Equinoxes. Apparent Motion of the Sun. Celestial Poles. Celestial Equator. Sun's Distance from the Earth variable. Perihelion and Aphelion. Angular, or Apparent Diameter. The Obliquity of the Ecliptic wisely ordained. Durations of the different seasons.

THE earth not only rotates about its axis, but it also revolves about the sun, in an elliptical orbit, once in 365 days, 5 hrs., 48 min., 46 seconds. This we call a year. The change in the length of our days, and the change of our seasons, are a consequence of the earth's motion around the sun.

Aristarchus,[1] B. C. 270, discovered that the axis of the earth was not perpendicular to the plane of the ecliptic; and that this obliquity of the ecliptic, as it is called, was the cause of the change of seasons as the earth pursued its path about the sun. Let us inquire into this change of seasons, and see how it is caused.

[1] Aristarchus was the first to endeavor to find the sun's distance from the earth.

The path of the earth around the sun is called the *ecliptic.* It came to be named the ecliptic, because when the sun or moon is *eclipsed*, it is in this circle. This we shall see when we come to talk about eclipses.

Now, the earth's axis is not set perpendicular to the plane of the ecliptic. If it were, the equator and ecliptic would lie in the same plane. The axis is inclined so as to make the angle between the equator and ecliptic about 23½ degrees. This limits the sun's declination to 23½ degrees; and it is this obliquity of the ecliptic, too, that places the Arctic and Antarctic circles 23½ degrees from the poles, and the tropics of Cancer and Capricorn 23½ degrees from the equator. When I was a boy I used to wonder why geographers did not place these imaginary circles at 23 or 24 degrees, and not bother us with the fraction.

The axis of the earth *points always in the same direction.* Hence, at our summer solstice, June 21, it is inclined *toward* the sun to its greatest possible extent; and at our winter solstice, December 21, it is inclined *from* the sun to its greatest possible extent. On the 21st of June, then, the North Frigid zone is entirely illuminated, and it is constant day; the South Frigid zone receives no light from the sun, and it is constant night.

On the 21st of December the North Frigid zone receives no light, and it is constant night; while the South Frigid zone is entirely illuminated, and it has continual day.

At the equinoxes, March 21 and September 21 (that is, when the sun crosses the equator), one half of the earth is illuminated from pole to pole.

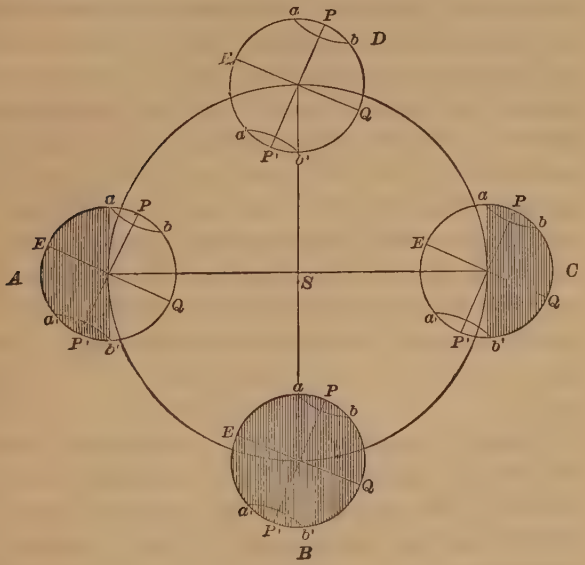

FIG. 2.

NOTE. It is to be noted that this figure, like all others in the book, is out of scale, and very much exaggerated. The earth's orbit, for example, is represented as a circle, though we know it to be an ellipse.

In the diagram (Fig. 2), let S be the sun, and A, B, C, D, the earth in four positions in its orbit; P P′ the axis of the earth, and E Q the equator. A represents it on the 21st of June, C on the 21st of December, B on the 21st of September, and D on the 21st of March. Let, also, a b and a′ b′ be the Arctic and Antarctic circles. At A, the summer solstice, the North Frigid zone is entirely illuminated, and the days are evidently longer than the nights everywhere in the northern hemisphere. At C, the winter solstice, the North Frigid zone will receive no light from the sun, and the days in the northern hemisphere are shorter than the nights. At B, the autumnal equinox, and at D, the vernal equinox, the earth is illuminated from pole to pole, and the days and nights are equal all over the world, — which, indeed, is the reason why these points are called the *equinoxes*. At the equator the days and nights are always equal.

If you will attentively study the diagram, you will see all this very clearly; and you will see also that the seasons in the southern hemispheres are just the reverse of ours. When I said the sun "crosses the equator," I referred to the *apparent* motion of the sun. It is the earth that moves. We very frequently speak of the sun moving, meaning its apparent motion. Thus we say the sun rises and sets; but we know that

it is the motion of the earth upon its axis that causes it to rise and set. And I will take occasion here to tell you that the prolongation of the earth's axis to the sphere of the heavens marks what we call the celestial poles, and the extension of the plane of the equator is the celestial equator, or the equinoctial.

But what causes the change of seasons? Is it because we are nearer the sun at some times than at others, the orbit of the earth being an ellipse with the sun in one of the foci? No, strange to say, that has nothing to do with it. We are, in point of fact, nearer the sun in January than in July.

The change of seasons is caused by the different angle at which we receive the sun's rays. In summer the sun attains its greatest altitude, we receive the rays more perpendicularly, and it is warm. In winter the sun is at its least altitude, we receive the rays more obliquely, and it is cold. At the equator the sun is never very far from the zenith, there is very little change in the seasons, and it is always warm. At the poles the sun never attains a greater altitude than 23½°, the rays are oblique, and it is generally cold. Moreover, in our summer the days are longer than the nights, and we have more of the sun's heat. In fact, from the time the sun crosses the equator on March 21, the days in the northern hemisphere are longer

than the nights, until it crosses it again on the 21st of September.

So we see the change of seasons is caused by the revolution of the earth about the sun, and the obliquity of the ecliptic.

I said that we are nearer the sun in January than in July. How do we ascertain this fact? The proof is very simple. You will see it in a minute. You know that if you hold an orange or anything else in your hand it appears larger when brought close up to the eye than when at a distance. The farther off it is held, the smaller it appears. That is, its *angular diameter* is less. By angular diameter we mean the angle it subtends at the eye.

Now when we measure the sun's angular diameter with a sextant, or other astronomical instrument, we find it to be greatest in January, and least in July; *ergo* the sun is nearest us in January, and farthest in July. When nearest the earth it is said to be in *perihelion*, and when farthest in *aphelion*.

You must not confound the angular diameter of a body with its *real* diameter. The former depends upon its distance and is measured in degrees, minutes, and seconds of arc; and, in the case of the sun, moon, and planets, is constantly changing; the latter is in miles and is of course always the same.

I have said that in the southern hemisphere the

seasons are the reverse of ours, — their winter is our summer, their spring our autumn; but I will call your attention to the fact that the inhabitants of that hemisphere are nearest the sun in their summer, and farthest off in their winter. This should make, in corresponding latitudes, their winters colder than ours and their summers warmer; and, indeed, Captain Sturt, who explored Australia, describes the heat in the interior of that vast island as beyond anything we have any conception of in our temperate zone.

Having explained to you the cause of the change of our seasons, I wish now to show you that this inclination of the earth's axis to the plane of the ecliptic has been ordained by a wise Providence. To illustrate this, I will make two suppositions: first, let us suppose that the axis of the earth lay in the plane of the ecliptic. The equator would then be at right angles to it. What would be the change in the seasons?

When the earth was in that part of its orbit directly east of the sun it would be illuminated from pole to pole, and the days and nights would be equal all over the world. As the earth moved northward, the southern hemisphere would receive more and more of the light of the sun, and the northern hemisphere would lose it, commencing at the pole. The

days would be growing longer in the southern hemisphere, and shorter in the northern one. When the earth was due north of the sun, the southern hemisphere would have a vertical sun, and constant day; and it would be intensely warm. The northern hemisphere would have no sun at all; it would be constant night, and intensely cold. As the earth moved on in its orbit, the northern hemisphere would receive more and more of the sun's rays, commencing at the equator, and the southern hemisphere would lose them. The days would be growing longer in the northern hemisphere and shorter in the southern one. When the earth was due west of the sun it would be illuminated from pole to pole, as in its eastern position, and the days and nights would be equal again all over the world. As the earth moved on, the southern hemisphere would lose the sun's light, commencing at the pole, and the northern one would receive more and more of it. The days would be growing shorter in the southern hemisphere and longer in the northern one. When the earth was due south of the sun, the northern hemisphere would have constant day, and extreme heat; and the southern one would have constant night, and intense cold.

It is readily seen that under this supposition the change of seasons would be too *violent;* and neither animal nor vegetable life could subsist.

Secondly, let us suppose the axis of the earth to be perpendicular to the plane of the ecliptic. The plane of the equator would then coincide with the plane of the ecliptic. Let us see what the change in the seasons would be.

In this case one half of the earth, from pole to pole, would be illuminated at all times of the year. It would not matter in what part of its orbit the earth happened to be. The days and night would be equal all over the world, at all times of the year. The torrid zone would enjoy perpetual summer; the temperate zones, spring; and the frigid zones, winter. That is, what we call these zones. Under the supposition there would be no Arctic and Antarctic circles, and no tropics of Cancer and Capricorn. There would be nothing to indicate these imaginary circles in either of my suppositions. The only change of seasons in this last case would be that owing to the difference in distance of the earth from the sun as it went round in its elliptical orbit. This would be so slight that we may say there would be no change of seasons.

In what we call the torrid zone animal and vegetable life could subsist under these circumstances; but probably not in what we call the temperate and frigid zones.

These two cases may be very easily illustrated by taking an apple to represent the earth and

thrusting a knitting-needle through the core to represent its axis. Let a candle be placed at the centre of a round table to indicate the sun, and the plane of the table will be the plane of the ecliptic. First, place the needle horizontally at the edge of the table, and carry the apple around the table, keeping the needle pointing always in the same direction, — and you will see the change of seasons as described under my first supposition.

Secondly, place the needle perpendicular to the table, and move the apple around it, and you will see at once that there can be no change of seasons, and that the days and nights must be equal all over the world at all times, as I have said.

The thoughtful student may inquire why the different seasons, — spring, summer, autumn, and winter, — are of unequal duration. If the earth moved with a uniform motion, in a circular orbit, this inequality would not exist. But the earth moves in an elliptical orbit, with the sun in one of its foci, and with variable velocities. In winter the earth has not only a shorter arc to pass over, but it is moving with a greater velocity than in summer.

Mons. Guillemin reckons the mean durations as follows: spring, 92.9 days; summer, 93.6 days; autumn, 89.7 days; winter, 89 days.

TALK THE THIRD.

Long Days and short Nights, and *vice versa*. Solstices. Equinoxes. Twilight. The Midnight Sun. Arctic Voyagers. Appearance of the Heavens to an Observer at the Poles; and at the Equator. Velocity of the Earth in its Orbit, and upon its Axis.

LET us now look into this matter of long days and short nights, and *vice versa*.

You know that our longest day is the 21st of June, when the sun is in that sign of the zodiac called Cancer, — hence the tropic of Cancer. The sun on that day attains its greatest distance north of the equator. This distance from the equator is called its *declination*, and its greatest possible is 23½ degrees; because that is the inclination of the equator to the ecliptic, as I have already told you.

Now when the sun is near its greatest declination it varies very little in its time of rising, and in its meridian altitude, from one day to another. For a few days before and after June 21 it rises at about the same hour, and attains about the same meridian altitude. This is simply owing to the fact that it changes its declination very

little from day to day. It is said that Thales, B. C. 600, observed this. He called it the solstice, from *sol*, the sun, and *stare*, to stand. Thus December 21 is our winter solstice and, theoretically, our coldest day; and June 21 our summer solstice and, theoretically, our warmest day. You remember that Scott says in the Lady of the Lake: —

> "And not the summer solstice there
> Tempered the midnight mountain air."

Let us take a certain day of the year, say the 21st of June, when the sun's declination is 23½ degrees north, and suppose four observers, A, B, C, D, to be at different points on the earth's surface. We will suppose A to be at the equator; B to be in latitude 23½° N.; C to be in latitude 60° N.; and D to be in latitude 66½° N., — that is, on the Arctic circle.

On the 21st of June the days are longer than the nights everywhere in the northern hemisphere, as we have seen. Between the vernal and autumnal equinoxes the days in the northern hemisphere are longer than the nights; and the reverse in the southern hemisphere. Let us look at our observer A. His days and nights are equal. The sun rises at six in the morning, and sets at six in the evening. It bears at rising east-northeast, and at setting west-northwest.

Now let us look at our observer B. As his latitude is the same as the declination of the sun, the latter will be, at noon, directly over his head, — that is, in his zenith. Here I will call your attention to a singular fact: as the observer's latitude is the same as the declination of the sun, you would naturally expect the sun to rise in the east point and set in the west point of the compass. But this is not so; it rises a little to the northward of east-northeast and sets a little to the northward of west-northwest; and, what is more, it will continue to rise more and more to the northward and to set more and more to the northward as we proceed north; though it will always be south of us at noon. This is owing to the obliquity of the ecliptic, which I have said so much about.

To B the sun will rise at 20 minutes past 5 in the morning, and set at 40 minutes past 6 in the evening. His days will be 13 hrs. 20 min. long, and his nights 10 hrs. 40 min. long.

Let us now go to our observer, C, in latitude 60° N. Here the sun at rising bears north-northeast, and at setting, north-northwest. It rises at a quarter before 3 in the morning, and sets at a quarter past 9 in the evening. The day is 18 hrs. 30 min. long, and the night but 5 hrs. 30 min. long. But in consequence of the "twilight" our observer would have no night at all; or, I had better say, he would have

no darkness. He would be able to read a book at midnight without the aid of artificial light.

Let us see what twilight is. It is due to the reflective power of the atmosphere. If the atmosphere did not reflect light, we would be in darkness whenever we passed out of the direct rays of the sun; and the transition from day to night would be instantaneous, and there would be no such thing as twilight.

Now, an observer sees some of the reflected rays of the sun until it has reached a circle 18 degrees below the horizon. This circle is called the *crepusculum*. The duration of twilight depends mainly upon the latitude of the observer and the declination of the sun. It is a simple problem to work out. We first calculate the time of the sun's setting. This we do by solving a right-angled spherical triangle, of which we have given two sides, viz.: the latitude, and the complement of the declination of the sun, or the polar distance, as it is called. With the two

[1] A writer in the New York "Home Journal," of April 10, 1889, speaking of the *Azores*, or Western Islands, which are in 38° north latitude, says: "It was the first day of June when we arrived at Fayal. In these southern (sic) latitudes balmy summer twilights close in the dark shadows of night almost without warning. There is no afterglow; no tender gloaming, no lengthening out of daylight." And again, in a letter of May 1, the same writer says of Fayal (latitude 38° north): "The fish caught in these southern (sic) waters exceed in brilliant coloring their comrades of northern climes." And this from Boston!!

known sides, then, we compute the angle at the pole, and this is the sun's hour angle, or the local time of sunset.

We then suppose the sun to be 18 degrees below the horizon, and again find the sun's hour angle. We have in this case to solve an oblique spherical triangle, of which we have given the three sides, viz.: the complement of the latitude, and the sun's polar distance, as before, and the sun's altitude, which is minus 18°. The hour angle, when found, will be the time of the end of twilight; and the difference between this time and the time of sunset will be the duration of twilight.

Now to our observer C, in latitude 60° N., the sun will not, after setting, go as far below the horizon as 18 degrees, and he will have twilight all night, as I have said. In the tropics, that is, to an observer in the tropics, the sun descends nearly at right angles to the horizon, and soon reaches the *crepusculum;* hence the twilight is short. In high latitudes the sun descends obliquely, and takes longer to reach the *crepusculum;* hence the twilight is long. It is least at the equator, and greatest at the poles.

We will now join our observer D, whom we supposed to be in latitude 66½° N., or on the Arctic circle. His day would be 24 hours long. The sun would not set at all. At noon it would bear due south, and would be 47 degrees high,

that is, 47 degrees above the horizon. It would then descend, in an oblique direction, towards the horizon, and moving to the northward and westward, would at midnight just touch the horizon, and bear due north.[1] It would then commence to rise again and begin another day. (I am neglecting the effect of refraction, which I will explain farther on.) This is what is called the "midnight sun." It is customary for the English tourists to go every summer to Norway to observe it. Not that this spectacle is peculiar to Norway. Do not get that idea into your heads. You can see the midnight

[1] And yet this paragraph has been going the round of our papers, unquestioned. It is hardly necessary to say that if the observer was "looking west," he would not see the sun at all; still less would he see it rise there. —

"SUNSET AND SUNRISE IN NORWAY. — Imagine yourself in a ship at anchor looking west, or straight in front of you. There is a broad expanse of sea a little to your right hand, behind you will be the rugged coast, and to your left the long, narrow fiord between the islands and the main land that the steamer has just traversed. You watch the sun as it slowly, slowly sets; the islands and the coasts look like a dark rich purple, and the shadows cast by the ship's masts grow longer and longer. After a bit, when the sun has sunk apparently twelve feet from the horizon, it stops and seems to remain stationary for about twenty minutes; then the very seagulls hide away, while the air all of a sudden strikes chilly. Each one has an awed, expectant feeling. Anon the sun rises very slowly once again, and the yellow clouds change with his uprising to even greater beauty; first to the palest primrose and then to a bluish pink. The sky, which was just now rose-color, becomes gray, then pale emerald green, and eventually rock after rock stands out, caught by the sun's rays, and the reign of day has begun once more." — *From "A Jubilee Jaunt."*

sun anywhere on the Arctic circle on the 21st of June. Europeans go to Norway to observe it, because Norway is accessible. Americans might go to Greenland to do so, and I wonder our "sight-seers" do not. You have perhaps read Du Chaillu's book, entitled, "The Land of the Midnight Sun." He applies the name to Norway and Lapland; but, as I have just said, these countries are no more entitled to it than Greenland, Siberia, or Alaska.

I read once of an Englishman who journeyed to Norway expressly to see the midnight sun. He gave his servant orders to call him long enough before midnight to give him time to rise and dress. Upon being called, he turned over in bed and remarked that he really felt too tired to rise, "but that he would come back again next year!" If any of you should ever go to, say, Discoe, in Greenland, to observe this interesting spectacle, I hope you will not imitate this Englishman's bad example.

But you must not gather from what I have said that the midnight sun is only to be seen on the Arctic circle. As soon as the sun has crossed the equator, on March 21, the whole of the north pole is illuminated, and, as the sun's declination increases, so does a corresponding portion of the earth's surface about the pole receive more and more light. For example: on May 1 the declination of the sun

is 15° N., and a zone 15 degrees from the north pole is constantly illuminated. Within this circle it is continual day, and the inhabitants have a midnight sun. If a man wished to be on the circle where he could *just* see it, — as in the case of our observer on the Arctic circle on the 21st of June, — he would have to be on the 1st of May in latitude 75° N. This, to fully comprehend, you must *think out* for yourselves.

Let us go back again to our observer whom we left on the Arctic circle on the 21st of June. The sun now begins to move toward the equator; its declination decreases daily; and if our observer should travel north just as many degrees or minutes as the declination decreases, he would continue to see the sun just *grazing* his northern horizon at midnight. Suppose that on the 21st of June he had been in latitude 75° 30′ N., instead of in latitude 66° 30′ N. The sun at noon would have been 38° above the horizon, bearing south; and at midnight it would have been 9° above the horizon, bearing north.

At the poles the days are six months long, and the nights the same. At the north pole the day begins at the vernal equinox, and ends with the autumnal equinox. But twilight at the poles lasts one and a half months; and "refraction" also assists to make the days a little longer.

You have all read of the Arctic voyagers and their long nights. In latitude 78° north the night is four months long; that is, the sun is that time below the horizon. Fortunately the moon, unlike the sun, changes its declination very rapidly, so that in the course of a year it crosses the equator very often. And whenever it is far enough from its extreme southern declination, our voyagers will be cheered by its light. To an Arctic voyager in latitude 78° N. the moon would be visible as soon as it attained a declination of 12° south; and after it attained a declination of 12° north it would not set at all. There would be a moon bearing south, and a moon bearing north, just as we have seen with the sun.

Of course the return of the sun is anxiously looked for by these hardy mariners; and about the time it may be expected to be seen, all hands are on the lookout for it. Some go aloft, so that they may be the first to see it. You know as well as I do that the higher we ascend the farther we can see. This is owing to the fact that the earth is a sphere; and when I come to explain to you what we call the "Dip of the Horizon," I will tell you how much farther we can see; but this by the way. On one of the ships sent to look for Sir John Franklin (who, you recollect, went in 1845 with two ships to search for a northwest passage to the Pacific Ocean, and

who with all of his officers and men perished), the officers edited for the amusement of the crew a small sheet called the "Illustrated Arctic News." One of the pictures represented the sun just peeping above the southern horizon. In the foreground was a ship frozen up in the ice, and near by was a party of sailors gazing intently at the sun, throwing their caps in the air and dancing for joy. It was called "The Prodigal's Return."

Now if I have made myself plain, and if you will draw a few diagrams to assist you, and then give this subject some hours' *thought*, I am sure you will fully comprehend this matter of the length of the days in different latitudes, which, simple as it is, seems not to be generally understood.

After the 21st of June the days in the northern hemisphere grow shorter and shorter until the autumnal equinox, September 21, when the days and nights are equal all over the world. From this time until the vernal equinox our nights are longer than the days. And in the southern hemisphere the seasons are the reverse of ours, which I have purposely repeated more than once.

Where would a man go on the earth's surface in order to see all the stars in the heavens? To

the equator; for there he would see, in the course of six months, all the visible stars from the north pole to the south pole. I am supposing the observer to view the stars with the naked eye, at night only.

Where would he go to see the least number? To the poles; for at the north pole he would see only the stars of the northern hemisphere, and at the south pole those belonging to the southern hemisphere. At intermediate points he would see more or less, as he approached or receded from the equator.

In latitude 40° north we see all the stars of the northern hemisphere, and all those belonging to the southern hemisphere which are not nearer the south pole than forty degrees.

Let us suppose a man to be at the north pole, and see what the appearance of the heavens would be to him. The north star, Polaris, would be nearly in his zenith; that is, nearly overhead. If it were exactly at the pole of the heavens, it would be directly in the zenith; but it is really about 1° 18′ removed from the pole. We will, however, neglect this, and consider it to be in the zenith of our observer.

All the other stars in the northern hemisphere would be always above his horizon, and his horizon would be the plane of the equator. The stars would not rise or set, but would move

around our observer in circles parallel to the horizon. They would all be circumpolar stars. A star of no declination would go around on the horizon, and all the others would describe circles parallel to it, at altitudes corresponding to their declinations.

If the sun were north of the equator, — that is, any time between March 21 and September 21, — it would be constant day, and the sun itself would go round in a circle parallel to the horizon, and at a height above it corresponding to its declination. On the 21st of June, for instance, it would be 23½ degrees high, and that would be its greatest possible altitude. If the sun were south of the equator, — that is, between September 21 and March 21, — it would be constant night. When the moon was in north declination it would be constantly visible; as soon as it crossed the equator to south declination it would disappear. Our observer would have no time. He could not, therefore, speak of having a good time, or a bad time. *He would n't have any time at all.* How could he have? There would be nothing to indicate it. The stars would not rise in the east and set in the west. *He would not have any east and west points.* He could not say it was twelve o'clock when the sun was on his meridian. *He would n't have any meridian.* When he started to return to happier climes he would not, at first, know whether he

was on his way to China or Peru. He would know nothing about the revolution of the earth about its axis, *for he would n't revolve.* He would simply face in different directions towards space. His north point would be directly over his head, and his south point directly under his feet. He would be in latitude 90°, and in longitude 0°. Since he had no time, he would have no longitude.

But you may object to my saying that when he started to return south he would not know what road to take, and ask, "Where is his compass?" Why would it not point out the north, south, east, and west points to our observer? Well, I must tell you that the needle points to the *magnetic* pole. Now the magnetic pole is not at the north pole of the earth, but is in about latitude 70° north and longitude 97° west. When a ship is in that latitude and longitude the needle, if freely suspended, will point downwards, — towards the *nadir*, in fact. But the compass we use is the mariner's compass. The needle is attached to a card and cannot point downwards; it is not freely suspended. When in high latitudes the card becomes very "sluggish," as sailors call it; it does not turn upon its pivot and fails to indicate the ship's course. This is on account of the "dip" of the needle. Arctic navigators find the compass almost useless in high latitudes. Still, I am not

sure but that a needle freely suspended might be of some slight use to our "man at the pole" in determining the direction to travel on his return south; but the north point of the needle would point south, if it "pointed" at all; and, taking all the circumstances in consideration, he would be somewhat in the position of Dickens' boy who was in the habit of taking a view of the surrounding scenery by standing on his head.

Let us now transport our observer to the equator, and see what the aspect of the heavens would be to him.

The north star (I am supposing it to be at the pole, and am disregarding the effect of refraction) would be on the northern horizon. If there were a star just at the south pole of the heavens it would be on the southern horizon. A star on the equator, — that is, a star of no declination, — would rise due east, pass directly overhead, and set due west. It would describe what astronomers call the prime vertical. All the other stars would rise in the east, at all points between north and south, and would describe vertical circles parallel to the prime vertical. They would all be above the horizon twelve hours, and below it twelve hours. There would be no circumpolar stars.

It would be the same with the sun. At the equinoxes the sun would rise due east, pass

directly overhead, and set due west. At other times it would describe a vertical circle either north or south of the prime vertical, and would at all times of the year be above the horizon twelve hours and below it twelve hours. And of course the moon would follow the same law.

You will find it instructive if you will imagine yourselves to be in different latitudes, and then *think out* the appearance of the heavens, the length of the day, etc. You must first assume a certain month and day, of course; and perhaps you are beginning by this time to agree with me that astronomy requires much abstract thought.

Shakspeare did not know much about even elementary astronomy, as I will point out to you some pages farther on; but he knew enough to make Hamlet say: "There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy."

If you have any curiosity to know how fast we are flying through space around the sun, you have only to divide the circumference of the earth's orbit by the number of days in a year. If you try this, you will find we are moving at an average rate of nineteen miles a second. And if you wish to know with what velocity we are whirling around the earth's axis,

you have only to divide the circumference of the earth by twenty-four, to find the hourly rate; or by 1440, to find the rate per minute. You will discover that at the equator the velocity is about seventeen miles a minute. Of course here in latitude 40° north, we are not revolving with such velocity, because it is not so many miles round the earth in an east and west direction; but any book on Mensuration will tell you how to find the distance round the earth in any latitude, knowing as we do the circumference at the equator.

What more shall I tell you about the earth? We have talked of its shape, size, motions, seasons, zones, etc. I do not propose to say anything about its structure, or its atmosphere, because books on geology and meteorology treat specifically of these subjects. I will, however, in a subsequent *talk*, have something to say of the effect of the air on refraction, and Columbus's discovery of the trade winds.

TALK THE FOURTH.

The Moon. Its shape. Its size. Its Distance from the Earth. Its motions. The Moon's Phases. Rule for finding the Moon's Age. Earth-shine, or Secondary Light. The Moon's Sidereal, and Synodic periods. Perigee and Apogee. Librations.

IN our last *talk* we confined ourselves to the Earth. Suppose we now turn our attention to its satellite, — our Moon.

Astronomers tell us that the moon is a round, dark, or non-luminous body, shining by the reflected light of the sun; 2,153 miles in diameter, and about 240,000 miles distant from the earth. That it is round needs no proof; we see that it is round. That it shines by reflected light is shown by its *phases*. Thales first discovered this, B. C. 600. Shakspeare says: —

> "The moon 's an arrant thief,
> And her pale fire she snatches from the sun."

The moon has three motions: it moves around the sun; it revolves about the earth; it turns upon its axis. How do we know this? We know that it moves around the sun because

it accompanies the earth in its orbit; we know it revolves about the earth by its *phases;* we know it rotates upon its axis by its always presenting to us the same face.

The moon is but 2,153 miles in diameter, while the sun is about 866,000 miles in diameter; yet the moon appears to be of about the same size as the sun. Why is this? Because it is so very much nearer. The sun is about 93 millions of miles off, while the moon is but about 240 thousands of miles off. The angular diameters are about the same (32½′) because the moon, though so very much smaller, is very much nearer.

Compared to the sun and most of the planets, our moon is very insignificant in size. Venus is of about the size of the earth, and if brought as near to us as the moon, would appear four times as large as the moon. But Venus, though nearer to us than any other planet, is never less than 25 millions of miles distant from the earth. Compare this with the moon's distance, and you will not wonder that the latter appears so much larger and brighter.

What do we mean by the phases of the moon? We refer to the different shapes this body assumes. Let us see what causes it to appear sometimes as a crescent, and at other times round.

You know that the earth, carrying with it the moon, revolves about the sun. The moon, too, revolves about the earth, though in a much smaller orbit. Now do you not see that the moon, in its revolution about the earth, must sometimes be between the earth and sun, sometimes at right angles to a line joining their centres, and sometimes it must have the earth between the sun and itself? A very simple

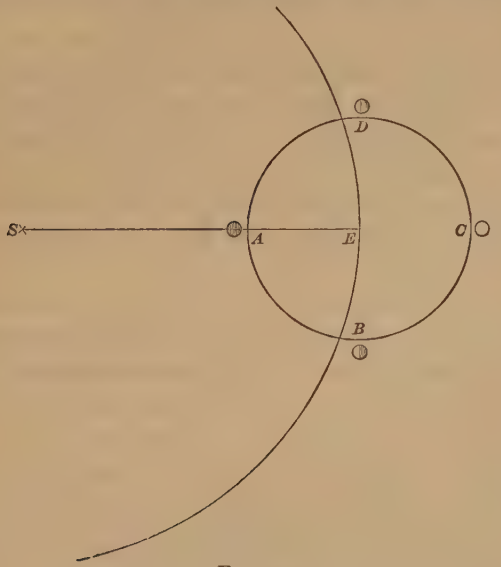

FIG. 3.

NOTE. It is to be observed that this diagram, like all others in the book, is much exaggerated and out of scale. In point of fact, E S is to E A nearly as 400 to 1; and the orbit of the moon is an ellipse, and not a circle.

diagram will serve to illustrate this; and we may suppose the earth to be at rest—the phenomenon will be the same.

Let S (Fig. 3) represent the sun; the point S is sufficient to indicate it. Let E be the earth in its orbit (only a portion of which is represented). It may for our purpose be represented by a point. The small circle, A, B, C, D, represents the orbit of the moon in its revolution around the earth. Let A be the position of the moon when it is between the earth and sun; B be its position when it has moved 90 degrees, and is at right angles to the line S E, joining the centres of the sun and earth; C be its position when it is in opposition to the sun as seen from the earth, the earth then being between it and the sun; and D its position after it has moved 90 degrees again.

Now, when the moon is at A, it is invisible.[1] It must be. All the light it receives from the sun is reflected back in the same direction. Its dark side is presented to us, and we do not, of

[1] The two points in the orbit corresponding to new and full moon respectively, are called by the common name of *syzygies;* those which are 90 degrees from the sun are called *quadratures*, and the points half way between the syzygies and quadratures are called *octants.* The circle which divides the enlightened from the unenlightened hemisphere of the moon is called the *circle of illumination;* that which divides the hemisphere that is turned towards us from the hemisphere that is turned from us, is called *the circle of the disk.*

course, see it. It then moves to the eastward of the sun, and appears as a crescent. Most of its light is reflected back in the direction of the sun, but some of it reaches the earth, and as the moon is a sphere, it is reflected in the form of a crescent. This is what we call the new moon. It is to be seen a little after sunset; and since it is in the same direction as the sun, and a little to the eastward of it, it follows that it must rise in the morning a short time after the sun has risen, and must set in the evening a short time after the sun has set. It has been above the horizon all day, but we have not seen it, on account of the sun's light; but as the sun sinks below the horizon and its light diminishes, the moon is seen as a very delicate crescent, and with its round limb towards the sun.

If we continue to watch it from night to night, we shall notice that on the second night after the new moon it is farther from the sun, and the crescent is larger. Being farther from the sun, it sets later in the evening. The third night it will be still farther from the sun; it will be larger and brighter and will set later; and so on, until about the seventh night, when it will be in the position B in our diagram. One half of it is now illuminated (that is, it reflects the sun's rays from half its face), and it is said to be in its first quarter. It will be on our meridian about the time the sun is setting, and we may

infer that it rose about noon. It has been visible all the afternoon, though we probably have not observed it.

Continuing our observations, we shall find the moon moving farther and farther from the sun; increasing in size and brilliancy, and setting later and later in the night, — until about the fourteenth or fifteenth day after the new moon, when it will have attained the position C in our diagram. It is now directly opposite the sun; it reflects all its rays to us, and it appears round. It is now what we call full moon. It rises as the sun sets. The full moon *must* rise as the sun sets, because it is opposite to it. We have the moon now all night. It rises when the sun sets, and sets as the sun rises.

The next night after full moon we observe that it rises about 50 minutes after sunset, and that it has very slightly diminished in size; that is, it is not quite a circle. The next night again it rises still later, and is still smaller; and so on until about the twenty-second day after new moon (or about 7½ days after full moon), when we find it rising about midnight. It is now in the position D in our diagram. One half of it is illuminated, as at B, and it is said to be in its last quarter. It is visible now in the forenoon, if we look for it.

From the last quarter it continues to rise later and later, and resumes its crescent shape,

precisely as it appeared between the positions A and B. In fact, from full moon we return through similar phases, in reversed order, to the new moon again. The moon then continues to approach the sun until it attains its first position, A, in our diagram, when the cycle recommences. As I have mentioned in our first *talk*, it is not seen for a day or two in every month. It is because it is between the earth and sun, or so near the sun as to be invisible to the naked eye.

From new moon to full moon it is said to *wax*, and from full moon to new moon to *wane*. From new moon to first quarter, and from last quarter to new moon, it is in form a crescent; between the first quarter and full moon, and between full moon and last quarter, it is gibbous; and when directly opposite the sun it is full.

After this explanation of the phases of the moon you can comprehend why Juliet says to Romeo: —

> "O, swear not by the moon, the *inconstant* moon
> That monthly changes in her circled orb,
> Lest that thy love prove likewise variable."

The moon was called *Selene* by the Greeks, and *Luna* by the Romans.

We have seen that the new moon must rise and set with the sun. When it is in its first

quarter, it rises about noon; when it is full, it rises at sunset; and when it is in its last quarter, it rises about midnight. Of course I am speaking generally as to these times, for the exact times depend upon the moon's right ascension and declination. But if you will think this out until you fully understand it, you will have learned a good deal; as, knowing the moon's age, you can at once make a very close mental calculation as to its time of rising. I will give you a rule for finding the moon's age. It is a good enough rule for practical purposes, and it renders you independent of almanacs. I have never found it in error more than a day.

TO FIND THE AGE OF THE MOON.

To the epact add the day of the month, and to this sum add the number of the month from March (inclusive). This sum, if less than 30, will be the age of the moon. Should the sum exceed 30, subtract 30 from it, and the remainder will be the moon's age.

The epact can be found in the Book of Common Prayer of the Episcopal Church, and in most almanacs. Note that the new epact begins in March, not January. I will give you an example to show the working of the rule: required the age of the moon Dec. 25, 1885.

Epact for 1885	=	14
Number of the month from March	=	10
Day of the month	=	25
Sum	=	49
Subtract		30
Moon's age	=	19

This will be four days after full moon, and we may infer that the moon will rise about 9 P. M.

Full moon, you know, must be fourteen or fifteen days old, and rises about 6 P. M., or sunset. The *exact* time of rising depends upon the declination of the moon and the latitude of the observer.

Did any of you ever happen to notice that our novelists make the moon to rise at any hour of the night to suit them? I am not referring to that abominable production called the "novelette," for of course in it, when the hero and heroine have a midnight interview, the full moon must be made to appear *coûte qu'il coûte!* But I have noticed in the writings of the best English and American authors such statements as, "Shortly after the sun went down the crescent moon appeared in the east." Indeed, in a popular magazine I read of this remarkable phenomenon; the time is early in the night, and the writer says: "Standing outside the door of the church, the young moon, *just risen over the mountains in the east*, they, etc." Dickens himself, in "Barnaby Rudge," says: "It was a fine

dry night, and the light of a young moon, *which was then just rising*, shed around that peace and tranquillity which gives to *evening time* its most delicious charm."

Do you not see how absurd such a statement is? how impossible it is? I could multiply examples of such errors if necessary to substantiate my position.[1] Even Captain Marryat, in his delightful story of "Midshipman Easy," speaks of "a *crescent-shaped* and *waning* moon being seen early in the evening." This cannot be. If the moon is crescent-shaped and seen early in the evening, it is *waxing*. A crescent-shaped and waning moon can be seen only after midnight. A waning moon seen early in the night is always a gibbous moon; for it must be after full moon since it is waning.

The mere fact that such expressions, so often occurring, are not taken notice of by the critics, convinces me that I am correct in my belief that even elementary astronomy is neglected in the education of our youths. Now that I have

[1] Lever, in his description of the advance of the British troops from Brussels (Charles O'Malley), speaks of the new moon being visible at one o'clock in the morning.

Rider Haggard, in "King Solomon's Mines," makes the new moon rise at sunset.

And even Coleridge, in his "Ancient Mariner," describing the approach of night, says: —

> "Till clomb above the eastern bar
> The *horned* moon, with one bright star
> Within the nether tip."

called your attention to it, I am sure you will in the course of your readings come across such astounding statements in regard to the appearance of the moon at critical moments that you will be ready to exclaim with Macbeth: —

> "Can such things be,
> And overcome us like a summer's cloud,
> Without our special wonder?"

though I will remark, *en passant*, that I shall have something to say concerning even Shakspeare's astronomical facts in another place.

You may have observed that when the new moon is first seen, the dark portion of the moon is also faintly to be traced with the naked eye. If you have never noticed this, do so at the next new moon if the weather should be clear. An old Scotch poet says: —

> "I saw the new moon late yestreen,
> Wi' the auld moon in her arm."

Galileo, in 1610, first explained this phenomenon. Let us see what the explanation of it is.

The new moon is seen nearly in a line with the sun. The bright crescent is the sun's light reflected to us by the moon, as you know. But the earth receives light from the sun (and to an observer on the moon is full), and this light is reflected back to the moon, and is again reflected by the moon back to us, thus causing the

entire outline of the moon to be seen, — faintly, because the sun's light has suffered a double reflection. As the moon waxes, and moves from the sun, this reflected light of the earth becomes less and less, and is overpowered by the increasing light of the moon; consequently the dark portion is no longer visible. If you will refer to the diagram, page 67, this appears very clearly. When the moon is near A, we see that the *earth-light* is reflected back to the moon; but when the moon has moved to B, only a small portion reaches it. As a rule the entire moon can be seen only for a few nights before and after new moon.

Some astronomers call this *earth-shine*, and others, *secondary light*.

The moon revolves about the earth, from west to east, in twenty-seven days, seven hours. But, as the earth has in that time moved to the eastward in its orbit around the sun, it takes the moon a longer time to attain the same *relative* position to the earth and sun; so that the time from new moon to new moon, or from full moon to full moon, is twenty-nine days, twelve hours; and this is what we call a *lunar month*. The first period, that is, twenty-seven days, seven hours, is the *sidereal month*. The sidereal month is the actual time it takes the moon to revolve about the earth, and the lunar month is what astronomers call a *synodic* period.

You recollect I told you that the moon revolves upon its axis, and yet we see but one side of the moon. Why is this? Since it revolves upon its axis, one would naturally think we should see all sides of the moon. Well, it revolves upon its axis in exactly the same time it takes to make one revolution about the earth; and this is the reason why it always presents the same face to us. This is what astronomers say; though it has been disputed, and the point has been much discussed.[1]

When the moon is nearest the earth in her revolution, she is said to be in *perigee;* and when farthest, in *apogee.*

As we have seen, the moon presents to us always the same face; but in consequence of what are called its *librations*, we see a little over its poles and a little around its equatorial edges, so that astronomers estimate that we see about four-sevenths of the entire surface of the moon. Of the remaining surface we know nothing and never shall; and if there be inhabitants there, they never see the earth.

[1] No one disputes the axial rotation of the moon, however, who understands the matter.

TALK THE FIFTH.

The Moon's angular or apparent Diameter. Its Distance from the Earth variable. Parallax. Horizontal Parallax. How it is found. Method of computing the Moon's Distance from the Earth, and its Diameter and Volume. Light shed by the Moon. Nodes. Physical Constitution of the Moon. Lunar Cycle. Influences. Tides. Attraction of Gravitation at Surface.

I HAVE said that the moon is *about* 240,000 miles distant from the earth. A good way to remember it is to consider it equal to sixty radii of the earth, taking the diameter of the earth to be eight thousand miles. When we measure the moon's angular diameter we find it varies considerably from time to time; *ergo*, the moon's distance from the earth varies.[1] Its least distance is 221,000 miles, and its greatest is 253,000 miles; a difference of 32,000 miles. I do not expect you to remember these exact figures, but I call your attention to them because they have an important bearing upon eclipses, which I will explain to you in our *talk* about the sun.

[1] Its orbit being elliptical.

Let us see how astronomers calculate the moon's distance from the earth. It would seem to be an abstruse problem, but I think I can show you that the *method* by which it is done is not at all difficult to comprehend. I recollect in reading Professor Airy's lectures he stated that one reason why he was induced to give popular lectures was that he had observed that persons visiting the Observatory at Greenwich always exhibited an air of incredulity when told about the magnitudes and distances of the heavenly bodies. They seemed to think, with Lord Dundreary, "that it was what no fellow could find out." Professor Airy was the Astronomer Royal of Great Britain, as you no doubt know.

Now in order to calculate the distance of the moon, we have first to find its horizontal parallax; knowing this, it is very easy to compute the distance, — and this applies to all the heavenly bodies; as soon as we know their parallax, we readily find their distances, diameters, and volumes. So I must first tell you what *parallax* is. Parallax is the change in the direction of an object as viewed from different places; or, it is the angle at the object made by two lines drawn from it to the two places. The *horizontal parallax* of a heavenly body is its change of direction as seen from the centre of the earth and the surface of the earth, — the body being on

the horizon, — or, it is the angle at the object subtended by the radius of the earth.

In the diagram (Fig. 4) suppose the circle A B C to represent the earth, O its centre, and let A be an observer on its surface. Let M be the moon on his horizon A M. The angle A M O is the moon's horizontal parallax.

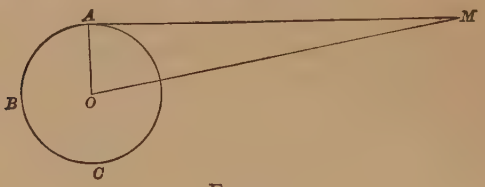

Fig. 4.

Now in order to find the moon's horizontal parallax, two observers, one as far north as practicable and the other as far south, and both being

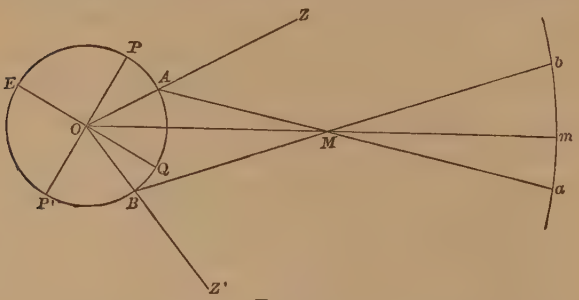

Fig. 5.

on the same meridian, observe the moon's zenith distance when it is on the meridian, and from these observations deduce the parallax required.

In the diagram (Fig. 5) let O be the centre of the earth, PP′ its axis, and E Q the equator. Let A be an observer in north latitude, and B an observer in south latitude. Let M be the moon on their meridian. The observer at A measures the zenith distance Z A M; the observer at B, the zenith distance Z′ B M. Knowing these angles we know the angles O A M and O B M. Then in the quadrilateral A O B M, we know the angles at A and B, and the angle A O B; also the two sides, A O, O B, they being radii of the earth. The angle A O B, you observe, is the difference of latitude of the two observers; so of course we know it. Now from these *data* we can find the angle A M B. Now the angle A M O is what we call the *parallax in altitude* at A, and the angle B M O the *parallax in altitude* at B. Knowing the parallax in altitude, we can by an easy formula compute the horizontal parallax required.

In the diagram the arc *a m b* represents an arc of the celestial sphere.

You see that in this method we use the earth as a base-line, as it were. And I may as well tell you here that the moon is the only heavenly body (save only the planet Mars) whose parallax can be determined in this way, and that, because it is so near. The mean horizontal parallax of the moon is $57' 3''$. I say the *mean*, because the distance of the moon varies, as I

have told you; and the parallax, you notice, depends upon the *distance* of an object. It has nothing to do with its size.

When we have found the horizontal parallax, the distance of the moon is easily computed. For, in the right-angled triangle, M A O (Fig. 4), we know the angle A M O (the horizontal parallax just found), and the side A O, the radius of the earth; whence we find O M, the distance of the moon from the earth. For example: —

$$\text{sine A M O} = \frac{\text{A O}}{\text{O M}},$$

or,

$$\text{sine A M O} \times \text{O M} = \text{A O};$$

whence,

$$\text{O M} = \text{A O, cosecant A M O.}$$

Now,

$$\text{A O} = 3950 \text{ miles, and A M O} = 57' 3''.$$

3950	log.	3.59660
57′ 3″	log. cosec.	11.78000
O M = 238,000	log.	5.37660

This gives us 238,000 miles for the mean distance of the moon.

Now, as soon as we have found the moon's distance, we can find its diameter in miles. For in the diagram (Fig. 6) let the circle M N represent the moon, O its centre, and O M its radius; and suppose E to be an observer on the earth's surface. The observer at E measures the angular diameter of the moon, that is, the angle M E N, the mean value of which he finds

to be 31′ 8″.8. One half of this is the angular semi-diameter, or the angle M E O. Now, in

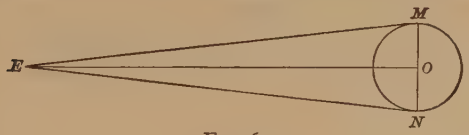

FIG. 6.

the right-angled triangle, E O M, we know E O (having just found it), and the angle M E O just measured; whence we find O M. For example:

$$\text{tang. M E O} = \frac{\text{O M}}{\text{O E}},$$

or,

$$\text{O M} = \text{O E tang. M E O.}$$

O E = 238,000 miles.	log.	5.37660
M E O = 15′ 34″.4	log. tang.	7.65589
O M = 1077.7 miles.	log.	3.03249

1077.7 multiplied by 2, gives us 2055 miles, as an approximate diameter for the moon.

Again, having found the moon's diameter, we can easily compute its volume; for we know that the volumes of two spheres are to each other as the cubes of their radii. Calling the radius of the earth R, and the radius of the moon r; the volume of the earth V, and the volume of the moon v, we have

$$R^3 : r^3 :: V : v,$$

in which proportion we know the first three terms. The volume of the moon is about one-fiftieth that of the earth.

Let us look back for a moment and survey the progressive steps by which we have attained to a knowledge of the moon's distance, diameter, and volume. We first measured a base-line on the earth's surface; then, by triangulation, we found the length of one degree of latitude, and this gave us the circumference and diameter of the earth. These enabled us to calculate the volume of the earth. We then used the earth for a base-line, and found the moon's horizontal parallax. With this, we found the moon's distance; having found the distance, we were enabled to compute its diameter; and knowing the diameter, we found its volume. All this, you see, came from the measurement of the base-line on the earth's surface. No wonder that such pains have been taken to make it as accurately as possible, and that the operation has been repeated in different parts of the world, as I explained to you in our first *talk*.

To give you an idea of the light shed by the moon, I must tell you that Mr. Lockyer estimates that it would require 547,513 full moons to give as much light as the sun.[1] He says: "Now there would not be room for so many in

[1] The earth receives very little *heat* from the moon's rays. Herschel suggested that the heat might be lost in dissipating the clouds, which certainly have a tendency to disappear under the rays of the full moon. Sailors frequently assert that the "moon will scoff the clouds away."

the half of the sky which is visible to us, as the full moon covers $\frac{1}{240000}$ of it; hence it follows that the light from a sky full of moons would not be so bright as sunshine." Think of that!

The orbit of the moon is inclined 5 degrees to the plane of the ecliptic. The moon, in its revolution about the earth, is constantly intersecting the plane of the ecliptic, and the points of intersection are called nodes. Thus we have the ascending node, and the descending node. The moon, too, changes its declination rapidly, and frequently crosses the earth's equator in the course of a year.

Let us now see what we know about the surface of the moon. Our largest telescopes bring it within two hundred and forty miles.[1] Not a very great distance, you observe.

We find its surface to be made up of mountains, valleys, and plains. Most of the mountains resemble extinct volcanoes. The surface has been accurately mapped, and the mountains, volcanoes, and continents named. The heights of these volcanoes have even been found; the highest is 27,000 feet high, which you observe is *relatively* higher than our highest mountain. In fact, the surface of the moon is much more broken up than the surface of the earth. Is it not wonderful that astronomers can calculate

[1] The Lick Observatory telescope brings it much nearer.

the heights of these mountains and volcanoes? How do you suppose it is done? They do it by means of an instrument called the micrometer, — an instrument used for measuring very small angles and spaces, as its name indicates. They measure the lengths of the shadows cast by these mountains when the sun is rising or setting at the moon; and from the lengths of these shadows they can calculate the corresponding heights. And I must tell you that some of these astronomers pass their entire lives in making observations on the moon alone. Photography has lent its aid, and beautiful views of the moon have been taken. So one need not wonder that so much is known about this luminary.

The moon has no atmosphere. This we know by the absence of clouds, and also from the fact that when it occults a star, the star disappears at once, and does not linger on the edge as it would do if there were an atmosphere. The fact that the moon has no atmosphere led the great humorist, John Phœnix, to say in his book that the common expressions, "The moon was gazing with an air of benevolence," or, "with an air of complacency," were incorrect and objectionable, the fact being that the moon had no air at all.

There are no signs of water at the moon. We see, then, that in the absence of air and water, it cannot be inhabited.

Moreover, it is conjectured by astronomers that, in the absence of an atmosphere to shield its surface, or prevent radiation, the surface is, in turn, hotter than boiling water, and colder than anything we have any idea of. The length of its day is 29½ of our days; so that each portion of its surface is, in turn, exposed to and shielded from the sun for 14¾ days. Scientists say that the moon may once have been inhabited, but that it is burnt out.[1] Not a pleasant thing for us to contemplate.

Our telescopes bring the moon within two hundred and forty miles. If we continue to make them larger, and consequently to bring the moon nearer, it is not unreasonable to suppose that at some future day astronomers may be able to discover if there are any signs that it was once inhabited.

The moon, being so much nearer to us than any other heavenly body, has naturally been the object of curiosity and speculation from time immemorial. Dr. Holmes, in his delightful "Autocrat at the Breakfast Table," tells us that "once upon a time" it was arranged that at a given instant every man, woman, and child on the surface of the globe should give a loud scream, or yell; the idea being to encourage the inhabitants of the moon (if there were any)

[1] The latest observations with Lord Rosse's telescope, Professor Langley (I believe) says, make this doubtful.

to give an answering shout. When the time came, the only persons that screamed were a deaf man on one of the Feejee Islands, and an old woman in Pekin. All the others, in anticipation of the dreadful noise, had stuffed their ears with cotton, and neglected to scream themselves. However true this story may be, it is a fact that "once upon a time" it was seriously proposed by astronomers to erect on the plains of Tartary an immense structure, so large as to attract attention at the moon. It was hoped that the people there would, in answer, erect a similar one.

Not long ago I was asked by some very intelligent and cultured ladies if the moon could ever be seen in the daytime. Of course it can. It is above the horizon in the daytime during one half of its revolution about the earth. It cannot be seen for a few days after the new moon, because the sun's light overpowers it; but from about the time it is six days old it can be seen from its time of rising, and is visible in the afternoon. At the time of full moon it is above the horizon only at night.[1] In its last quarter it is visible all the forenoon.

You sometimes hear persons speak of a "wet moon," or a "dry moon," referring to its appear-

[1] I am speaking of the temperate zone. Within the Arctic circle the moon is above the horizon for days when it is at its greatest declination, as I have said in chapter iii.

ance at new moon. If the horns of the crescent point upwards, so that — as the Indians say — "you can hang a powder-horn upon it," it is said to be a "dry moon." It is hardly necessary to say that the position of the crescent depends upon the declination of the moon.

Every nineteen years the phases of the moon will recur in precisely the same order and on the same days. If, for example, in any year the new moon occurs on the 15th of June, it will occur again on the 15th of June nineteen years after. This is called the *lunar cycle*, and it was known some centuries before Christ. The lunar cycle was discovered by Meton, a Greek astronomer who lived at Athens in the fifth century before Christ. It was called the Metonic cycle. It is still preserved by the churches in their computation of Easter, under the name of the Golden Number, — so called, because the Athenians adopted it about 400 B. C. for the regulation of their calendar, and had it inscribed in letters of gold on the walls of the temple of Minerva.

Meton observed that two hundred and thirty-five revolutions of the moon are very nearly nineteen revolutions of the sun, and one complete revolution of the moon's node. Anthon's Classical Dictionary says on this subject: "'It has been suspected,' observes Dr. Hale, 'and

not without foundation, that the celebrated lunar cycle of nineteen years which Meton introduced into Greece for the adjustment of their lunar year with the solar, was borrowed from the ancient Jewish tables. This was the opinion of the learned Anatolius, bishop of Laodicea, about A. D. 270.' "

Suppose I speak now of the influences of the moon. The most important is its effect upon the waters of the earth, producing what we call tides. Tides are caused by the attraction of both the sun[1] and moon; but the latter being so much nearer the earth, its effect is much greater. It does not lie within the scope of my plan to enter fully upon this subject; but I may tell you that, speaking generally, when the moon is on the meridian it attracts the water and heaps it up, as it were, causing high tide. It pulls the earth at the same time towards itself more than it does the waters under the earth, thus causing a high tide on the other side. Hence there must be two high tides in every lunar day (24 hours, 51 minutes), and also two low tides. Theoretically, it should be high water at a place when the moon is on the meridian of that place;

[1] Shakspeare says: "The sun 's a thief, and with his great attraction robs the vast sea." He also says: "For the fortune of us that are the moon's men doth ebb and flow like the sea; being governed, *as the sea is, by the moon!*" — *Henry IV.*

Query: How did Shakspeare know this?

but tides, like the winds, are very much modified by local causes. Since it is the moon that principally causes the tides, high water at any place occurs about fifty minutes later from day to day, just as the moon rises later by that time. You must not confound *currents* with the tides. We find currents in every ocean; the Gulf Stream and the Japanese current are notable examples. We are not always able to explain the cause of the ocean currents; we only know that they exist, and observation tells us their velocity. I suppose you know what is meant by a town being at the head of tide water on a river; but if not, I will tell you that the tides of the ocean flow up all rivers a certain distance, and then stop. This marks the head of tide water; below this, the tide ebbs and flows. Above this point the waters, like the waters of the historical Tombigbee, always *run down*. Perhaps you may remember that Lander, who first descended the Niger River, looked eagerly for signs of "tide;" and in later days, Strain, who crossed the Isthmus of Darien and who descended the Chuquinaque to the Pacific Ocean, — half-starved and floating on a raft, — with what joy he welcomed the signs of "tide" and salt water. But this *en passant*.

It is popularly believed that the moon affects the weather, the crops, meat, and fish. It is even said that persons sleeping in its full light

will have their features drawn awry. None of these things are true. Arago, a French astronomer who examined the records for many years back, says there is no evidence to show that the moon affects the weather; and I have seen half the crew of a Line-of-Battle ship asleep under the light of a full moon, not once, but many times, and not a man of them ever "made a face." It used to be thought that madmen became more violent under a full moon; indeed, we get the word lunatic from *luna*, the moon. Thus Milton says, in "Paradise Lost:"—

> "Moping melancholy,
> And moon-struck madness."

I am inclined to believe, however, that madmen, like other people, are subject to bright influences.

One thing more I will speak of before I conclude this long *talk*. The moon being much smaller than the earth (its mass being about $\frac{1}{80}$ of the earth), the attraction of gravitation at its surface is much less than the earth's at its surface. It is calculated that a man there could jump six times as high as on the earth. So you see that if any of my young readers were transported to the moon, and should there attempt a "german" or quadrille, they would find themselves dancing as Queen Elizabeth is said, by Lord Melville, to have danced, — that is, "high and disposedly."

TALK THE SIXTH.

The Sun. Its Shape. Size. Motion. Distance. Relative Distances of the Planets from the Sun. Transits of Venus. Sun's Parallax. How determined. Method of finding the Sun's Distance, Diameter, and Volume. Disk. Photosphere. Point at which Sun rises.

HAVING finished our *talks* about the earth and moon, let us now turn our attention to our great luminary, the Sun, — the centre of our system. What do we know about it?

Astronomers have discovered that it is a round, incandescent mass, about 866,000 miles in diameter, and that it turns upon its axis once in from 25 to 28 days. It is distant from the earth about 93,000,000 miles.

Let us first see how its distance is determined; and you will appreciate the importance of this problem when I tell you that upon its determination depend the distances of all the planets from the sun, and from the earth. And I may say, too, their diameters and volume; for we have seen that these are derived from a knowledge of their distances from the earth.

Before the distance of the sun was known, astronomers knew the *relative* distances of the earth and planets from the sun, but not their *real* distances. For example: they knew that Venus was seven-tenths as far from the sun as the earth is, and Mars about one and six-tenths as far. I will explain to you farther on how they found this out. But you see that with the knowledge they had, as soon as the sun's real distance became known, the others followed.

As in the case of the moon, the sun's distance is readily calculated as soon as we can discover its parallax. The parallax of the sun is the angle subtended by the earth's radius as seen from the sun. I only repeat what I told you in our last *talk;* but I wish you to fully understand the meaning of parallax.

The planet Venus sometimes passes directly between the earth and the sun. It is projected on the face of the sun as a round, black spot. This is called a transit of Venus. Unfortunately these transits occur very rarely, the intervals between them being 8, 105, 8, 122 years, and so on.

In 1691 the English astronomer, Halley, pointed out that the parallax of the sun could be determined by these transits, and earnestly requested astronomers to take advantage of the transit to occur in 1761, which he, of course, could not hope to live to see. The first observ-

ations were made in 1761, and again in 1769. These observations have to be made at places far apart on the earth's surface, and one of the objects of the last voyage of Captain Cook (the great English navigator) was to observe the transit of 1769, which he did at the Society islands, in the Pacific ocean.

The method by which the parallax of the sun is deduced from these observations, is too abstruse to be explained here. No doubt many of those employed in making the observations and calculations spent years in the preparation for it. We will simply accept the fact that the parallax of the sun can be determined in this way.

The observations of 1769 gave for the parallax $8''.6+$. Think of this for a moment. The sun is so distant that the radius of the earth (about four thousand miles) subtends at the sun only an angle of $8''.6$. Why, we could not pretend to draw this on a scale; the angle would not be the thickness of a hair.

The sun's radius subtends at the earth an angle of about $16'$; this is small enough, but it is much greater than the angle subtended by the earth's radius at the sun, because the sun is very much larger than the earth. Compare them: The sun is 866,000 miles in diameter, and the earth barely 8,000. The angular diameter of the sun is about $32'$; the angular

diameter of the earth (measured at the sun) is about $17''$.

A transit of Venus occurred in 1874, and another in 1882; and both were observed with great care, for there will not be another one until 2004, — 115 years hence. Expeditions were sent by the European and American nations to different places. I think there were as many in all as forty-six. The Americans had stations at Chatham island, Kerguelen island, and other places. The observations have not yet been worked out; so the new determination of the sun's parallax has not been published. Although the principle is quite easy to understand, the calculations are very complicated. Our Grand Observatory is the earth, and *it is in motion*. Do you not see how this must complicate all celestial observations? Photography has lent its aid to assist in the observations of these transits, and views were taken at the different stations at the last transit.

The result, when published, will not probably differ much from the parallax now accepted, say $8'.81$. I believe astronomers only expect to make a change in the third figure, — that is, in the hundredth part of a second. We are interested in the result for more reasons than one. A change in the sun's parallax involves a change in its distance; and that, again, involves a change in the distances of the planets. But

suppose our astronomers should find the sun's parallax to be considerably increased? What would that indicate? Why, that the earth is much nearer the sun than in 1769. Now, if the earth should once begin to approach the sun, it would move with a greatly accelerating velocity, — since the law of gravitation (discovered by Sir Isaac Newton in 1682) shows that the attraction of gravitation decreases as the square of the distance increases, and *the reverse*, — and it would soon fall into the sun, and be consumed.

In point of fact, however, if we should find a considerable difference in the parallax, we should be more inclined to attribute it to the imperfection of the instruments used in the observations of 1769; for we *know* that the earth is not approaching the sun, — except that it is nearer to it at times than at others, as it should be, its orbit being an ellipse with the sun in one of the foci.

How do we *know* that the earth is not falling into the sun? Simply because the *sun's angular diameter remains the same.* We do not want any better proof than this.

There is another method by which the sun's distance can be found, and that is by first finding the distance of the planet Mars from the earth. Two observers — one at Greenwich, the other at the Cape of Good Hope — made

precisely the same observations of Mars, as I have described in the case of the moon, and found its parallax and distance from the earth. When Mars is in opposition (as it was when the observations were made), its distance from the earth is about one third of the distance of the sun from the earth. Hence, having found its distance, we multiply it by 3, and get the distance of the sun from the earth.

This method is not considered so accurate as the method of finding the distance by a transit of Venus, but it gives for the sun's distance 91½ millions of miles, — a close approximation.[1]

We cannot find the parallax of the sun by the method we use in finding the parallax of the moon or Mars, because it is so far off. The entire diameter of the earth would not give us a base-line long enough.

Having found the sun's parallax, we find its distance, diameter, and volume, precisely as we do in the case of the moon. I have given you its distance and diameter; its volume is about 1,300,000 times that of the earth.

The sun turns upon its axis once in about 25 days. How in the world did astronomers find this out? Let us see. The *disk* of a heavenly body is its face as it appears projected on the sky. We see on the sun's disk certain

[1] Recent observations, however, with the heliometer have given good results from Mars.

spots. Galileo first called attention to them in 1611. I am sure you all must have noticed that the papers frequently speak of there being spots on the sun.

Astronomers carefully observe these spots, and notice that they make their appearance on one edge of the sun's disk, and that they take about 12½ days to traverse it. Now, as the spots preserve their relative positions to each other, we do not suppose them to move across the face of the sun, but rather that the sun *revolves* and carries them with it. There is some uncertainty as to the exact time of the sun's rotation, but it is between 25 and 28 days.

Is the sun inhabited? This seems a foolish question to ask, does it not? If it is really an incandescent globe, of course it is not; but if the incandescence is confined to its photosphere (as some scientists think), and the surface of its globe is protected by a dense atmosphere, it may be inhabited.[1]

We have no evidence that the sun has lost any of its heat from the beginning of the world. Where, then, does it get its supply of fuel? We do not know, and probably never will know. The question belongs to what we may call *speculative* astronomy. Many such questions

[1] Hardly any astronomers think so, however.

arise, and some astronomers spend their lives in attempting to find the explanation of them.

Theoretical astronomy is an *exact* science. We can calculate the positions of the heavenly bodies, their dimensions, their motions, predict eclipses and occultations, find the latitude and longitude, etc., with absolute accuracy; but such questions as the nebular hypothesis, or how the stars and planets were first formed; the physical constitution of the sun and planets, etc., are for the present speculative. We may safely leave them to the great astronomers of the world.

The earth, as seen from the sun, would appear as a star of the fifth or sixth magnitude. Venus which is about the size of the earth, appears to us as a very bright star. It is about thirty-six million miles from us when in conjunction; remove it to a distance of ninety-two million miles, and it would appear to us as the earth appears to the sun; that is, as a very insignificant star. The sun itself, brilliant as it appears to us, sinks into insignificance in comparison to the fixed stars, which you know are themselves suns, and probably each one the centre of a system, just as our sun is. Why, do you know that if the sun were removed to the distance of the *nearest* star (alpha Centauri), it would appear to us as

a star of the second magnitude! It is almost impossible to comprehend such a statement.

The sun's bright surface is called the photosphere. The photosphere is simply what we see of the sun; whether it be the body of the sun, or simply its atmosphere or clouds. Do we know any of the materials of this photosphere? Yes; we have discovered them by means of the spectroscope. We have discovered that certain substances are burning in the sun and stars, and we find them to be nearly the same in all. These observations, known as the "Spectrum Analysis," tell us that the elements sodium, iron, magnesium, barium, copper, zinc, calcium, chromium, nickel, and others *are present in the sun* in the gaseous condition. In the stars, sodium, magnesium, iron, and perhaps hydrogen and barium. Our knowledge in this direction is constantly increasing, many astronomers giving their entire attention to this subject.

In the case of the moon, which has no atmosphere, we view it through a telescope and discover land, volcanoes, beds of oceans (dry), etc. It has no photosphere.

You remember that in our first *talk* I promised to say something more in relation to the exact point in the east at which the sun rises at different seasons of the year. It never rises at precisely the same point for two successive days.

You must have observed that in summer it rises well up towards the north, and in winter down towards the south. When it crosses the equator it rises due east to an observer, it matters not what latitude he may be in. On no other days of the year does it rise due east. After the vernal equinox, and until the autumnal equinox, it rises north of east and sets north of west to all observers in north latitude; and the farther north the observer, the farther to the north does the sun rise and set. In winter, that is, our winter, the sun rises south of east and sets south of west.

Shakspeare did not know this; for in "Julius Cæsar," in a dispute as to the east point, Casca says, —

"You shall confess that you are both deceived.
Here, as I point my sword, the sun arises;
Which is a great way growing on the south,
Weighing the youthful season of the year,
Some two months hence, up higher toward the north
He first presents his fire; and the high east
Stands, as the Capitol, directly here."

Casca was in error. As the time was the *ides* of March, that is, the 15th day of March, the sun rose only two degrees south of the east point, or we may call it directly or due east. "Some two months hence," that is, May 15, it would rise to an observer at Rome about east-north-

east; though Casca evidently meant to say that it will then, and not till then, rise due east.

While upon this subject I will call to your notice that Shakspeare pays little attention to astronomical facts. For example, in "Midsummer Night's Dream," at the opening of the play, Theseus says to Hippolyta, —

> "Four happy days bring in
> Another moon; but oh! methinks how slow
> This old moon wanes, etc.," —

referring to their approaching nuptials. Yet only a night or two after, the clowns — who are preparing to act a piece in celebration of the marriage — have a discussion at the rehearsal as to whether there will be a moon that night. Thus, —

Snug. Doth the moon shine that night we play our play?
Bottom. A calendar! a calendar! look in the almanac; find out moon-shine.
Quince. Yes, it doth shine that night.

and we know that one of them acted moonshine accordingly. Either Theseus was mistaken, or the almanac was incorrect, certainly.

It shows how little attention the literary men of the last century paid to the science of astronomy; for Steevens, Farmer, Malone, Dr. Johnson, and other commentators, never (so far as I have observed) take any notice of these

inaccuracies, though the proper reading of Shakspeare's plays has been the subject of controversy ever since they were first published. Volumes have been written on the subject.

I have already called your attention to the fact that the authors and critics of the present day are guilty of the same oversight.

TALK THE SEVENTH.

Eclipses. Occultations. A Solar Eclipse. Total, Annular, and Partial Eclipses. Digits. Lunar Eclipse. Inclination of Moon's Orbit to Plane of the Ecliptic. Number of Eclipses in a Year. Cycle of Eclipses. Sun's Influences. Its Light and Heat.

NOW that we know something about the sun and moon, suppose we turn our attention to the eclipses of these bodies.

When the moon passes directly between the earth and sun, the latter is said to be eclipsed; and when the earth is between the sun and the moon, the moon is eclipsed. There is a difference between an occultation and an eclipse, though we are apt to consider them synonymous terms. Eclipse is from the Greek, and means a disappearance; occultation is from *occultare*, to hide. When the moon is eclipsed it is in the shadow cast by the earth, and it disappears. When a star is hidden from sight in consequence of the moon passing between it and the earth (a thing which happens very frequently) it is called an occultation. Thus, we speak of the occultations of Jupiter's satellites,

which are caused by Jupiter passing in front of, and hiding them from our view. When the satellites pass into the shadow cast by Jupiter, they are eclipsed. I suppose we may say that an occultation is an eclipse, but an eclipse is not an occultation.

Let us first consider an eclipse of the sun, or a solar eclipse. When the moon is directly between the earth and the sun, that is, you observe, at the time of new moon, we have an eclipse of the sun. It may be total, annular, or partial.

If the centre of the moon passes directly over the centre of the sun, and if, moreover, the moon is in that part of its orbit nearest the earth, it produces a total eclipse. The shadow cast by the moon (which you observe is conical in shape) reaches the earth, though it is never very large, its diameter averaging about 150 miles. But to all observers in this shadow the sun entirely disappears, and it is *eclipsed.* A total eclipse is very rare, and never lasts over eight minutes at any one place.

Now, suppose the centre of the moon to pass directly over the centre of the sun, but let the moon be in that part of its orbit farthest from the earth. In this case the shadow cast by the moon does not quite reach the earth, and an observer on the earth's surface, situated in a line with the centres of the two bodies, will witness

that uncommon phenomenon called an annular eclipse. The moon does not *quite* cover the face of the sun; its angular diameter is a little less than the sun's; and we see a bright narrow ring of light encircling the dark body of the moon, — hence annular, from *annulus*, a ring.

Just as the moon would appear to us if we should hold a silver dollar between us and it. When we hold the coin close to the eye, the moon is not seen; but if we hold it farther and farther off, keeping its centre over the centre of the moon, we can finally hold it where it does not entirely cover it, but leaves a bright ring visible. An annular eclipse occurs very, very rarely.

Most of the eclipses of the sun are what we call *partial*. The centre of the moon does not pass directly over the centre of the sun, and consequently only a portion of the sun's disk is obscured. For the sake of distinction astronomers imagine the diameter of the sun to be divided into twelve equal parts, called *digits*, and the number of *digits* obscured is stated. Thus, an eclipse of nine *digits* would indicate that three-fourths of the sun's face is obscured; and this applies also to the moon in a lunar eclipse.

When the earth is between the sun and the moon, and the latter passes into the shadow cast

by the earth, we have a lunar eclipse, or an eclipse of the moon. It may be total, or partial, and you observe can happen only at full moon. If the moon is near, but not at, a node, we have a partial eclipse. When the moon passes through the centre of the shadow, it is totally eclipsed. But even in this case the moon's disk is scarcely ever wholly obscured. The sun's light is bent by the earth's atmosphere, by what we call refraction, towards the moon, and sometimes tinges it with a ruddy color. In an eclipse of the moon the shadow of the earth as cast upon the moon is seen to be circular, which is one of the proofs that the earth is round.

It is to be observed that an eclipse of the moon is visible to the whole side of the earth turned away from the sun, because the shadow cast by the earth is so large; whereas, as we have seen, an eclipse of the sun is visible over a small area, because the shadow cast by the moon is small.

Now you will very naturally ask why we do not have a solar eclipse at every new moon, and a lunar eclipse at every full moon. If the orbit of the moon coincided with the plane of the ecliptic, we *would* have these eclipses every month. But it does not. It is inclined to the ecliptic 5°, and consequently the moon very rarely passes exactly between the earth and sun, nor does it often pass through the earth's

shadow. It *generally* passes above or below the sun, and above or below the earth's shadow.

In fact, the greatest number of eclipses that can occur in any one year is seven, and the least, two. Astronomers can calculate them with the utmost accuracy for years ahead. The Chinese learned to do so centuries ago; and it is said that Thales, about 585 B. C., was able to predict one.

You may remember that Columbus, during his fourth voyage in 1504, was wrecked on the island of Jamaica, and was dependent upon the natives for a supply of provisions. The Indians becoming negligent, or refusing to continue the supply, Columbus, who knew that an eclipse of the moon was about to take place, called them together, and told them the Great Spirit was displeased with them, and on a certain night would hide his face. When the moon became dark, the Indians, convinced of the truth of his words, hastened to bring supplies of food as usual.[1]

Just as we have seen that every nineteen years the moon's phases will recur in the same order, — which period of nineteen years we call the lunar cycle, — so will eclipses recur in precisely

[1] This anecdote is related by Irving in his "Life of Columbus." He quotes Las Casas as an authority. It should be taken *cum grano salis;* for, I believe, astronomers have calculated that no eclipse of the moon happened at the date given.

the same order every eighteen years and eleven days. This is called the cycle of eclipses, and it was known to the ancient Chaldeans and Greeks under the name of *Saros;* and by its means eclipses were predicted before astronomy had made much progress.

Let us now glance at some of the benign influences of the sun. We know that our earth is lit up by its beams and warmed by its heat. But this is not all. Mr. Norman Lockyer says, in his astronomy: —

"There is something else besides light and heat in the sun's rays, and to this something we owe the fact that the earth is clad with verdure; that in the tropics, where the sun shines always in its might, vegetable life is most luxuriant, and that with us the spring-time, when the sun regains its power, is marked by a new birth of flowers.

"There comes from the sun, besides its light and heat, *chemical* force, which separates carbon from oxygen, and turns the gas which, were it to accumulate, would kill all men and animals, into the life of plants. Thus, then, does the sun build up the vegetable world."

Again, we are apt to think that the earth receives *all* of the light and heat radiated by the sun. Mr. Lockyer tells us that we receive less than one billionth part of it; and further, that all the planets together receive but one two hun-

dred and twenty-seven millionth part of the solar light and heat. He estimates that the *whole* heat of the sun collected on a mass of ice as large as the earth would be sufficient to melt it in two minutes, to boil the water thus produced in two minutes more, and to turn it all into steam in a quarter of an hour from the time it was first applied.

TALK THE EIGHTH.

Recapitulation. The Planets. Those known to the Ancients. Discovery of Uranus and Neptune. Inferior and Superior Planets. Satellites. Discovery of the Satellites of Jupiter and Mars. Speculations of Bishop Wilkins and others concerning the Moon. The Elephant in the Moon. Mercury: its Size, Distance from Sun, and Motions. Inferior and Superior Conjunctions. Quadratures. Phases. Transits. Venus: its Size, Distance from Sun, and Motions. Phases. Transits. Mars: its Size, Distance from Sun, and Motions. Opposition and Conjunction. Jupiter, Saturn, Uranus, and Neptune. Bode's Law. The Satellites of Jupiter.

BEFORE taking up the subject of the planets, let us go back again and see what we have learned thus far in regard to the motions, dimensions, distances, and volumes of the earth, moon, and sun.

We have learned that the earth is an oblate spheroid, turning upon its axis from west to east once in 23 hrs., 56 min., 4 seconds, and moving in an elliptical orbit around the sun once in about 365¼ days. By measuring a base-line on its surface, we found the length of one degree

of latitude, and from that its circumference, diameter, and volume. Having found the size of the earth, we next found the horizontal parallax of the moon, from which we calculated its distance, diameter, and volume. We found the moon had three motions, and that in consequence of one of them (its revolution about the earth), and the fact that it shines by reflected light, it exhibited phases. In the case of the sun, we discovered the time of its rotation by observations on its spots; and by a transit of Venus we found its parallax, and hence its distance, diameter, and volume. The size of the earth, the distance and size of the moon and sun, all depended upon the measurement of one small base-line on the earth's surface.

Now let us turn our attention to the planets. Our solar system comprehends the sun, as a centre, and the planets Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. I will speak of the asteroids in another place.

The sun is supposed to be at rest; and all the planets revolve about it, from west to east, in elliptical orbits. They also rotate upon their axes, from west to east, and all are dark bodies and shine by reflected light.

The planets Mercury, Venus, Mars, Jupiter, and Saturn, were known and named by the an-

cients. Uranus was discovered in 1781 by Sir William Herschel, and Neptune in 1846 by Dr. Galle of Berlin, who had previously been instructed by Le Verrier where to look for it. The discovery of this planet is justly considered one of the greatest triumphs of science. Owing to certain irregular motions of the planet Uranus in its orbit, — *perturbations*, as they are called, — astronomers were led to suppose that they might be occasioned by the existence of another planet outside of its orbit. Under this supposition alone, Adams, an English astronomer, and Le Verrier, a French astronomer, actually calculated *where* this supposititious planet should be. Singular to say, neither knew of the other being engaged in the same work; yet their calculations agreed very nearly, and the result was the discovery of the planet Neptune.

Mercury and Venus are between the earth and the sun, and are called inferior planets; the others are outside the earth's orbit, and are called superior planets. This has no reference to their size. The planets are distinguished as *primaries*, and their satellites are termed *secondaries*.

Most of the planets have satellites or moons. The Earth has one, Mars two, Jupiter four, Saturn eight, Uranus four, and Neptune probably one. These satellites, excepting the moon, were not known to the ancients, because they cannot

be seen with the naked eye. They were not discovered until the telescope was invented. Galileo, who first used it, immediately discovered the moons of Jupiter. His telescope was a very rude one, but the moons of Jupiter require but a small magnifying power to become visible. As telescopes were improved and made more powerful, the moons of Saturn and Uranus were discovered; but, strange to say, the moons of Mars were not seen until 1877, — only a few years ago. They were discovered by Professor A. Hall of the United States Navy, at the Washington Observatory.

I presume you have all read "Gulliver's Travels," — a fictitious work written by Dean Swift, in the reign of Queen Anne. One of the travels is called "A Voyage to Laputa." It was doubtless intended as a satire on the astronomers of the day. Well, Gulliver says of the astronomers on the imaginary island of Laputa: "They have likewise discovered two lesser stars or satellites, which revolve about Mars, whereof the innermost is distant from the centre of the primary planet exactly three of his diameters, and the outermost five." Rather a remarkable prediction in a work of fiction to be verified; but Swift is not the only writer who, in a freak of fancy, has anticipated the discoveries of Science.

Soon after the invention of the telescope, scientific men looked for great discoveries, par-

ticularly in the direction of the moon. The Royal Society of England was founded about this time, and the wits of the age were accustomed to ridicule its labors. Among its founders was Bishop Wilkins, who about the year 1650 published a work entitled "The Discovery of a New World," alluding to the moon. If the scientists of the day indulged in as wild speculations as the Bishop, one cannot wonder that they were ridiculed. I will give a few extracts from his work to illustrate what I said upon the subject in our *talks* about the moon. In his discourse to prove that the "moon may be an habitable world," he says, —

"'T is the opinion of Kepler that as soon as the Art of flying is found out, some of their Nation will make one of the first Colonies that shall transplant into that other World. I suppose his appropriating this Preheminence to his own Countrymen may arise from an over-partial Affection to them. But yet thus far I agree with him, that whenever that Art is invented, or any other, whereby a Man may be conveyed some twenty Miles high, or thereabout, then 't is not altogether improbable that some or other may be successful in this attempt."

Speaking of the "Gibbosities" of the moon, he says, —

"Now if you should ask a reason why there should be such a multitude of these in that Planet, the same Kepler shall jest you out an Answer. Supposing (saith

he) that those Inhabitants are bigger than any of us, in the same proportion as their days are longer than ours, —*viz.* by fifteen Times,—it may be, for want of Stones to erect such vast Houses as were requisite for their Bodies, they are fain to dig great round Hollows in the Earth, where they may both procure Water for their Thirst, and turning about with the Shade, may avoid those great Heats which otherwise they would be liable unto."

And again, —

"Kepler calls this World [the Moon] by the Name of *Levania*, from a Hebrew word which signifies the Moon, and our Earth by the Name of *Volva, a volvendo*, because it does by Reason of its diurnal Revolution appear unto them constantly to turn round; and therefore he stiles those, who live in that Hemisphere which is towards us, by the Title of *Subvolvani*, because they enjoy the Sight of this Earth, and the others *Privolvani, quia sunt privati conspectu volvæ*, because they are deprived of this Privilege."

It was to hold up to ridicule such writings as the above that Butler (the author of "Hudibras") wrote his satire entitled "The Elephant in the Moon," — the "elephant" being nothing more nor less than a mouse which had gotten in between the eye piece and the object-glass of the telescope. This satire appeared somewhere about 1665–70. In Sprat's "History of the Royal Society" appeared a "*Relation of the* Pico Teneriffe, *received from some considerable*

Merchants, and Men worthy of Credit, who went to the Top of it," in which it was stated that the inhabitants of the Canary Islands whistle so loud as to be heard five miles off; "and that to be in the same room with them when they whistle, were enough to endanger breaking the *Tympanum* of the Ear." Butler says in his satire, —

> "Or Men that used to whistle loud enough
> To be heard by others plainly five Miles off,
> Cause all the rest, we own, and have avow'd
> To be believed as desperately loud."

In this day I presume a whistle can be heard quite five miles, *through a telephone.*

MERCURY.

Let us commence with Mercury, the nearest planet to the sun.

Its diameter is about 3,000 miles, and its mean distance from the sun about 56,000,000 miles; it turns upon its axis once in 24 hrs., 5 min.,[1] and it makes one revolution about the sun in 88 days. Its day, then, is about the length of ours, and its year is about one fourth as long as ours. Its volume is one nineteenth that of the earth.

In the diagram (Fig. 7) let S be the sun, E the earth, and M, M′, M″, M‴, be Mercury in four different positions in its orbit. Since the earth and Mercury move around the sun with

[1] See note, page 137.

different velocities, they will have all possible *relative* positions with respect to each other; so we may, for the purpose of illustration, suppose the earth to be at rest in its orbit. Let E E′ represent the orbit of the earth, and M, M′, M″, the orbit of Mercury.

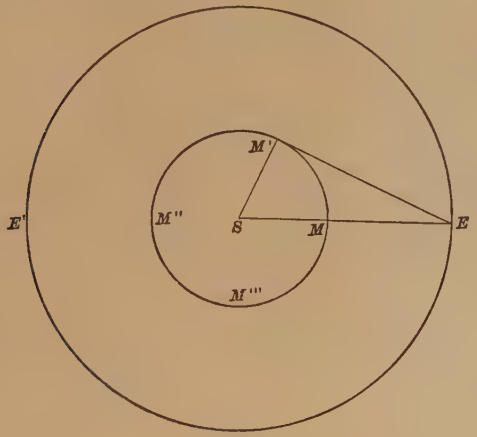

FIG. 7.

We see from this diagram that Mercury can never be in *opposition* to the sun; that is, seen in a line directly opposite the sun. Hence it can never be on the meridian at midnight, nor can it be above the horizon at midnight.[1] It can go, indeed, but twenty-nine degrees from the sun, and consequently it is rarely to be seen

[1] Pope says:

"And Venus sets ere Mercury can rise" —

which is an absurdity.

with the naked eye. It is generally so near the sun that the sun's light overpowers it.

When Mercury is at M, it is between the earth and sun, and is said to be in inferior conjunction. When it is at M″, the sun is between it and the earth, and it is said to be in superior conjunction. When in either of these two positions it must rise and set with the sun, and it is not visible. You see this at once; since it is *in a line* with the sun, it must rise and set with it.

The positions M′, M‴, represent its points of greatest eastern and western elongations, or *quadratures*. Its greatest *angular* distance from the sun is represented by the angle M′ E S, or M‴ E S, and it can never exceed 29 degrees. When Mercury is west of the sun it will rise before it, and will appear (if it can be seen at all with the naked eye) as a morning star. When it is east of the sun, it will set after the sun, and will be an evening star.

You perceive from the diagram that its distance from the earth varies very much. It is nearest to us at M (inferior conjunction), and farthest at M″ (superior conjunction). What is the difference between these two distances? A glance at the diagram shows it to be the entire diameter of Mercury's orbit, or about 112 millions of miles.

Again, since Mercury shines by reflected light, it should exhibit *phases*. It does when

viewed through a telescope. Galileo in 1611 discovered that Venus exhibited phases as soon as he turned the telescope to it. After what I have told you of the moon's phases, you will at once see that Mercury, a little after it has moved from the position M, will appear as a crescent; at M′, M‴, one half of it will be illuminated, and at M″ it will be full.

Since it is so much nearer to us at M, it should appear much larger, should it not? It does; its angular diameter as measured from the earth is 2½ times more at M than at M″.

When should we see it to most advantage, at M, M′, or M″? If we take the distance, only, into consideration, we would say at M, where it appears so much larger. But it then only shows as a crescent, and is, besides, too near the sun to be seen to advantage. If we consider the light reflected by it, we would say at M″, because it is full. But then it is farthest off, and appears at its smallest, besides being so near the sun again.

It is brightest, in fact, at the positions M′, M‴, because, although only one half of it is illuminated, it is farthest from the sun (as we view it), and is less affected by its light.

When Mercury is at its inferior conjunction it sometimes, though very rarely, passes across the face of the sun. This is called a *transit* of

Mercury. Astronomers cannot make use of it to determine the sun's parallax, as they do in the case of a transit of Venus. If the orbits of Venus and Mercury coincided with the plane of the ecliptic, there would be *transits* at every inferior conjunction. But they do not; just as we have seen that an eclipse of the sun does not happen at every new moon.

What more do we know about Mercury? Its nearness to the sun prevents us from obtaining any very accurate knowledge of its surface; but it consists of land and water, and is supposed to have an atmosphere; and I may as well tell you here that all the planets are, so far as we know, similar to the earth. Lockyer says that a mountain in the southern hemisphere of Mercury is estimated to be 11 miles high.[1]

VENUS.

We come now to Venus, the brightest of the planets, though far from being the largest. Its brightness is owing to its nearness. Its diameter is about 7,600 miles, and its mean distance from the sun is about 67,000,000 miles. It turns upon its axis once in 23 hrs. 16 min.,[1] and it revolves about the sun in 224 days.

[1] See note, page 137.

What I have just said concerning the different positions of Mercury in its orbit in relation to the earth, applies equally to Venus.

In the diagram (Fig. 8) let S be the sun, E the earth, and V, V′, V″, V‴, four positions of Venus in its orbit. Let E E′ represent the orbit of the earth, and V V′ V″ the orbit of Venus.

At V, Venus is in inferior conjunction; at V″, in superior conjunction; and at V′, V‴, in *quadrature*, or its greatest eastern and western elongations.

Venus never appears more than 47 degrees from the sun, and, of course, is never above the horizon at midnight.[1] The angle V′ E S, or the angle V‴ E S, can never exceed 47 degrees. For some months of the year Venus is west of the sun, rises before it, and is known as the morning star;[2] the remaining months it is east of the sun, sets after it, and is called the evening star, — "The star that bids the shepherd fold." When near the sun it is overpowered

[1] Yet Thompson, in the "Seasons" says: —

> "Sudden to heaven
> Thence weary vision turns; where leading soft
> The silent hours of love, with purest ray
> Sweet Venus shines; and from her genial rise,
> When daylight sickens, till it springs afresh,
> Unrivalled reigns, the fairest lamp of night" —

which seems to mean that Venus rises at sunset and shines all night, which is impossible.

[2] Venus is an evening star for about 9 months; for the next nine months she is a morning star.

light, and it is brightest near its points of elongation.

Its distance from the earth varies greatly; it being nearest to us at inferior conjunction, and farthest at superior conjunction, — the difference being the diameter of Venus' orbit; or

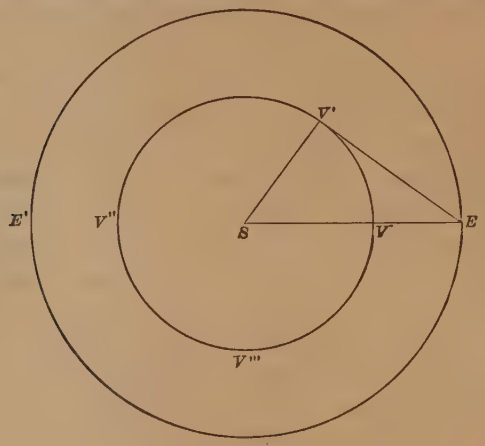

FIG. 8.

about one hundred and thirty-three millions of miles. It exhibits phases as Mercury does; and, as in the case of that planet, the angular diameter of the *crescent* is much larger than the diameter when *full;* it being then so much nearer. Indeed its angular diameter at inferior conjunction is about six and one-half times as great as when at superior conjunction. Venus can sometimes be seen in the daytime with the

naked eye. It is then at one of its points of greatest elongation, and is at its brightest. The earth, as viewed at Venus, would appear about as Venus does to us, — a little brighter, because it is somewhat larger.

Venus was called by the ancients Phosphorus or Lucifer, when the morning star; and Hesperus or Vesper, when the evening star, — hence "Vespers."

"How art thou fallen from heaven, O Lucifer, son of the morning!" — *Isaiah.*

"Hesperus, that led
The starry host, rode brightest, till the moon,
Rising in clouded majesty, at length
Apparent queen unveiled her peerless light,
And o'er the dark her silver mantle threw."
— *Milton.*

Astronomers tell us that Venus has an atmosphere and water; and Lockyer says that mountains are supposed to exist exceeding twenty miles in height![1]

One more point, and we will turn to another planet.

When Venus is at V′, in our diagram (Fig. 8), that is, at its greatest eastern elongation, the line E V′ being tangent to the circle V V′ V″ at the point V′, the angle E V′ S is a right angle. Now in the right-angled triangle E V′ S we know

[1] See note, page 137.

the angle S E V′; and, although we may not know the *actual* value of S E (*i. e.* the distance of the sun from the earth), we can find the *relative* distances of the earth and Venus from the sun. For, taking the mean value of the angle S E V′ to be 46°, we have —

$$\text{sine } 46° = \frac{S\ V'}{S\ E}$$

or, as the natural sine of 46° is .72 (the radius of the circle being assumed to be 1),

$$.72 = \frac{S\ V'}{S\ E};\ \text{hence S V′, or S V} = .72\ \text{S E.}$$

that is, the distance of Venus from the sun is about seven-tenths the distance of the earth from the sun.

You recollect I told you in a former *talk* that astronomers knew these *relative* distances before they knew the sun's actual distance from the earth. You see now that as soon as we can assign a positive value to S E in miles, S V becomes known also. We find S V by a transit of Venus, as I have described; and I will again repeat that upon this distance depends the distances of all the heavenly bodies, — save only the moon and the planet Mars. The moon's distance, and the distance of Mars you know we found by an independent method.

MARS.

The next planet is Mars. It is a superior planet; that is, its orbit is outside the earth's. Its diameter is about four thousand two hundred miles, and its mean distance from the sun is about one hundred and forty-one million miles. It turns upon its axis once in twenty-four hours, thirty-seven minutes; and it makes one complete revolution about the sun in six hundred and eighty-seven days. So while its day is about the same as ours, its year is equal to nearly two of ours.

In the diagram (Fig. 9) let S represent the sun, E the earth, and M, M′, M″, M‴, the planet Mars, in four positions in its orbit. We will suppose the earth to be at E, at rest in its orbit E E′.

When Mars is at M, it is said to be in *opposition* (that is, opposed to the sun); and when at M″, in *conjunction* (that is, conjoined with the sun). At M′, M‴, it is in *quadrature*. It is readily seen that when Mars is in opposition it is nearer the earth than at any other time. The difference in its distance at opposition and conjunction is the diameter of the earth's orbit; or about one hundred and eighty-five millions of miles!

Again, we see that when it is in conjunction, it must rise and set with the sun; whereas when it is in opposition, it must rise as the sun sets; and it will be upon the meridian about midnight.

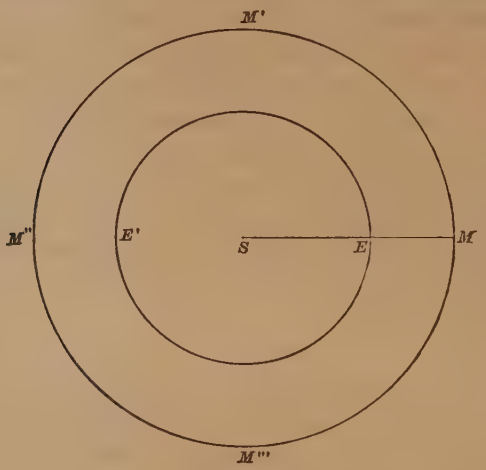

FIG. 9.

This is, of course, the best time to observe it, and astronomers take advantage of it. It was in this position (opposition) when the observations I have told you of were taken at Greenwich and the Cape of Good Hope to determine its parallax. Its angular diameter at opposition is seven times as great as in conjunction, as we might expect.

Mars is the only one of the superior planets that exhibits a marked *phase*. It sometimes appears *gibbous*.

Mr. Lockyer says: "Mars has not only land, water, and snow, like the earth, but also clouds and mists. The land is generally reddish when the planet's atmosphere is clear; this is due to the absorption of the atmosphere, as is the color of the setting sun with us. Hence the fiery red light by which Mars is distinguished in the heavens. The water appears of a greenish tinge."

JUPITER.

The next planet outside of Mars is Jupiter. It is not necessary to draw diagrams for it and the remaining planets, as Fig. 9 answers for all. The remarks as to Mars, in different positions in its orbit, applies to all the superior planets.

Jupiter is the largest and, excepting Venus, the brightest of all the planets. Its diameter is about 86,000 miles, and its mean distance from the sun is about 480,000,000 miles. It turns upon its axis once in 9 hrs. 55 min., and makes one complete revolution about the sun in about 12 of our years.

We here are struck with the fact that while Mercury, Venus, the Earth, and Mars, rotate in about the same time (24 hours), Jupiter, though so very much larger, rotates in about 10 hours. Now, as the earth is supposed to have assumed its spheroidal shape in consequence of its rotation, we should expect to find Jupiter very much

flattened at the poles. *It is;* the polar diameter being to its equatorial diameter as 16 to 17; while the earth's is only as 299 to 300.

Mr. Lockyer says of Jupiter: "It is surrounded by an atmosphere so densely laden with clouds that of the actual surface we know nothing."

SATURN.

The next planet is Saturn. Its diameter is about 70,000 miles, and its mean distance from the sun is about 882,000,000 miles. It rotates in 10 hrs. 14 min., and revolves about the sun in about 29½ of our years.

Saturn differs from the other planets in being surrounded by a series of rings. Astronomers are not yet agreed as to what these rings are composed of. The question belongs to what I have called speculative astronomy, and we will leave it to those who are spending years of their lives in trying to fathom it.

URANUS.

Our next planet is Uranus. It is about 32,000 miles in diameter, and its mean distance from the sun is about 1¾ billions of miles. It revolves about the sun in about 84 of our years. We do not know the time of its rotation because there are no spots on its surface to observe.

NEPTUNE.

The last planet is Neptune, — so far off as to be invisible to the naked eye. Its diameter is about 35,000 miles, and its mean distance from the sun about 2¾ billions of miles. It revolves about the sun in about 165 of our years. We do not know its time of rotation, nor do we know anything about its surface.

Although I have given you the distances of the planets from the sun, I do not expect you to remember these exact figures. It is common in popular astronomies to give an idea of the distances of the heavenly bodies by calculations as to how long it would take to reach them, by cars, etc. I have much the same opinion of the value of such illustrations as the late John Phœnix, who says in his book: "It is a curious and interesting fact, much dwelt on in popular treatises on astronomy, that were a cannon-ball fired from the earth to Saturn, it would be 180 years in getting there. The only useful deduction that we are able to make from this fact, however, is that the inhabitants of Saturn — if warned of their danger by the sight of the flash, or the sound of the explosion — would have ample opportunity, in the course of the 180 years, to dodge the shot."

I can, however, give you a rule by which you can always calculate the distance of the planets from the sun, supposing you to remember (as you should do) the distance of the earth from the sun. It is called Bode's law.[1]

If we write down, —

0 3 6 12 24 48 96

(which you observe is, from the second term, simply a geometrical progression), and add 4 to each, we get, —

4 7 10 16 28 52 100

and this series of numbers represents very nearly the relative distances of the ancient planets from the sun. For example, —

4	7	10	16	28	52	100
Mercury.	Venus.	The Earth.	Mars.	——	Jupiter.	Saturn.

Thus, we see that Mercury's distance from the sun is to the earth's as 4 to 10; Venus's as 7 to 10; Saturn's as 100 to 10; and so on. It is very easy to remember this rule, and the distances are correct enough for the ordinary student. For example, the mean distance of Venus from the sun is about 67,000,000 miles; by Bode's law it is 65,000,000 miles.

You notice I left a blank under the number 28; this I will explain farther on.

I have said that most of the planets have

[1] Kepler was the first to discover Bode's Law. (Chambers's Encl.)

satellites, or moons. They all have but Mercury and Venus. So far as we know, they are similar to our moon, and have the same motions, — except that the satellites of Uranus and Neptune seem to have a retrograde motion; that is, they move from east to west, instead of from west to east, as the planets do.

Jupiter has four moons. You can see them with an ordinary opera-glass, if you will select a time when Jupiter comes on the meridian about midnight; that is, when Jupiter is nearest the earth and is better defined. The dimensions of these satellites have been calculated, and names assigned them. They are all (but one) somewhat larger than our moon.

They revolve about Jupiter, and, as a matter of course, sometimes pass across his disk (a transit); sometimes pass behind him (an occultation); and sometimes pass through his shadow (an eclipse). The occultations and eclipses occur very frequently, as you can imagine with four moons revolving about him.

Astronomers can calculate and predict the times of these eclipses and occultations for years ahead, *to the very second;* and use is made of them to determine the longitude, — that is, on shore; we cannot observe them at sea, as I will explain to you in another *talk*. But you see that what I said is true as to theoretical astronomy being an *exact* science.

TALK THE NINTH.

Recapitulation. Discovery of the Velocity of Light. The Asteroids. Are the Planets Inhabited? Change of Seasons at Jupiter and Mercury. Aberration of Light. Kepler's Laws. Determination of the Density and Mass of the Earth. Density of the Planets. The Planets' Motions in their Orbits.

BEFORE commencing this *talk*, let us look back on the last. We now know the names of the planets, their motions, distances from the sun, diameters, and volumes; the length of their years and days, and something about their physical constitution. We concluded our last *talk* with an allusion to the occultations of Jupiter's satellites.

We have seen that the telescope was first used by Galileo about the year 1610, and that he discovered the satellites of Jupiter. In 1675 Roemer, a Danish astronomer, discovered the velocity of light.[1] He found that light was not transmitted instantaneously, as had been previously supposed, but that it travelled at the rate of about 186,000 miles a second. Very rapid travelling, is it not? But if you will divide the

[1] See note at end of *talk*.

sun's distance from the earth by 185,000, you will find that light is about 500 seconds (or 8 minutes and 20 seconds) in reaching us from the sun; and of course much longer in reaching us from the stars, — hundreds, and even thousands, of years, astronomers say. Can you imagine it?

You know that *sound* travels about 1150 feet in a second; very slowly in comparison to light. The speed of a tortoise compared to a "streak of lightning."

Surveyors have made use of the velocity of sound to determine the length of a base-line. A gun is fired at one end of the line, and the observer at the other end watches the flash, and notes the number of seconds by his watch before he hears the sound. This multiplied by 1150 gives the length of the line in feet. To eliminate the effect of the wind, a gun is fired at each end of the line, and the mean time is taken. Of course, in this case the transmission of light is supposed to be instantaneous, which it is for so short a distance. This method of measuring a base-line is not much used now; it is not accurate enough.

But how did Roemer discover the velocity of light? By the eclipses of Jupiter's satellites. The *times* of these occultations are predicted (as I have told you) and inserted in the astronomical almanacs.

Now, Roemer observed that these eclipses happened 16 min. 26 sec. *later* when Jupiter was in conjunction than when it was in opposition. (See Fig. 8). Jupiter, you see, is about 185 millions of miles farther off when in conjunction than when in opposition.

What idea naturally occurred to Roemer? Why, that light did *not* travel instantaneously; but that it took 16 min. 26 sec. to traverse the diameter of the earth's orbit. This distance is about 185,000,000 miles; divide it by 16 min. 26 sec., or 986 seconds, and you have the velocity of light per second. Very simple, is it not? And I again call your attention to the manner in which astronomers go on building up the science, step by step, like the "House that Jack built." Jansen invents the telescope; with it Galileo discovers the satellites of Jupiter; and by the eclipses of these satellites, Roemer discovers the velocity of light.

The velocity of light can be, and has been, calculated by other methods, which it is not necessary in these *talks* to explain.[1]

I have said that the planets belonging to our system were Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Now, I am quite prepared to hear you say you have frequently seen in the papers that "a new planet had been discovered." This I must tell you about.

[1] See Encl. Brit. Article, Light.

The distance between Mars and Jupiter is very great. If you will look back to the series, given under Bode's Law, page 132, you will see I left a blank under the number 28. Astronomers finding that this Law gave the distances of the planets from the sun pretty nearly, provided they skipped 28 and placed Jupiter under 52, jumped to the conclusion that there must be a planet somewhere to fill the unoccupied place. Search being made, a very small planet was discovered in 1800 and named Ceres; and soon after, three others, — Juno, Pallas, and Vesta. The search has been continued with constantly improving telescopes, until now we know of about 265 of these very small bodies. They have all received names; but of course we cannot pretend to remember them.

These bodies are known as the *asteroids*, or *minor planets*. The theory in relation to them is, that "once upon a time" a large planet existed in this space, and that it burst into innumerable fragments; perhaps by coming into contact with some other celestial body.[1]

[1] Professor A. Hall of the U. S. Navy, the discoverer of the satellites of Mars, who has kindly looked over my MSS., writes me that astronomers doubt this theory. He also tells me that the times of rotation of Mercury and Venus are not well known, and that it is doubtful if any mountains on Mercury and Venus have been measured.

He suggests to me that Jupiter's satellites *may* have been seen by the Ancients from the tops of high mountains.

These asteroids are very small bodies, and they are invisible to the naked eye; indeed, it requires very careful observation with a powerful telescope to see them at all. The largest of them is but 228 miles in diameter. The force of gravity there must be very small. A man on one of them would spring with ease 60 feet high, and come down without a shock to his system. Indeed, on the least of them, a man would have to be careful not to practise gymnastic exercises at all. If, for instance, he should attempt the "high jump," he would perhaps ascend so high as to be beyond the attraction of gravitation of the asteroid. He would then be attracted by some other heavenly body, and would pass the remainder of his melancholy existence in whirling through space. To use Macbeth's words, —

"He 'd jump the life to come."

I have said that the planets are similar to our earth. One question presents itself: are they inhabited?

It is reasonable to suppose they are. Why should the earth, which is only one of the planets, alone be inhabited? But if they *are*, the inhabitants must be differently constituted physically from ourselves, as you must perceive.

Mercury, for instance, is thirty-six millions of miles from the sun, — a little more than one-third of our distance. It receives from the sun,

at times, ten times as much heat as the earth, never less than seven times as much. We could not live under such a temperature.

Neptune, nearly three billions of miles from the sun, receives only one-thousandth as much heat as we do. The climate of the Frigid Zone is nothing in comparison to its cold. We certainly could not support it.

Moreover, while the force of gravity on the surface of Mercury is but three-fifths of that at the earth's surface, the force of gravity on the surface of Jupiter is very much greater. We might stand the former, — it would make us more springy in our walk, — but not the latter. It is calculated that the force of gravity on the sun's surface is twenty-seven times as great as at the earth; and that if one of our inhabitants were carried there, he "would be literally crushed by his own weight."

Do you remember that in our *talk* about the Change of Seasons I made a supposition in reference to the inclination of the axis of the earth? I supposed the axis of the earth to be perpendicular to the plane of the ecliptic, and called your attention to the fact that there would be no change of seasons. Well, the axis of Jupiter has little or no inclination, and there is no change of seasons there. At Mercury, on the contrary, — his axis being greatly inclined, —

the change of seasons is violent, as I explained to you it would be if the angle between our equator and ecliptic were very much increased.

I have not yet told you anything about what is called the *Aberration of Light*. This is caused by the motion of the earth and the velocity of light. You know that in a rain-storm, should the air be absolutely at rest, the rain-drops fall perpendicularly, and a man exposed to them would receive them on the crown of his hat as long as he stood still; should he start to run, the drops *appear* to fall in a slanting direction, and will strike him in the face. It is just so with a ray of light, the earth being in motion. The effect is that a star seems to describe a small circle in the heavens.

The telescope, in observing a star, has to be pointed slightly in advance of the star, and there is an apparent displacement. When the motion of the earth is directly towards a star there is no aberration. It is greatest when the earth's motion is at right angles to the direction of the star. This you must clearly see, for it would be the same with our man in the rain.

I will not attempt to go farther into this subject; but will mention that the velocity of light has been determined by its aberration, and that the fact of there being an aberration is one of the proofs that the earth revolves about the

sun. The "correction" for aberration is a very small quantity; we have *diurnal* aberration, and *annual* aberration; corresponding to the daily and yearly motions of the earth.

Aberration was first explained by Bradley, the astronomer royal, somewhere about 1750. He was led to its explanation by observing the pennant of his boat while rowing on the Thames.

About the year 1610 an astronomer named Kepler announced three remarkable laws. They have been called empirical laws, — from the fact that although Kepler believed them to be true, he could not explain *why* they were true. This was reserved for Sir Isaac Newton, who some fifty years after, discovered the law of universal gravitation, which law explained Kepler's laws.

You should commit to memory these laws. They are as follows: —

1. Each planet describes round the sun an elliptical orbit, and the centre of the sun occupies one of the foci.

2. The radius-vector of a planet describes equal areas in equal times.

3. The squares of the periodic times of any two planets are proportional to the cubes of their mean distances from the sun.

The radius-vector is a line supposed to be drawn from the sun to the planet; and the

"periodic time" of a planet is the same thing as its year, or time of revolution about the sun.

You observe that by the third law, we can very readily calculate the distance of a planet from the sun, when we know its periodic time, which is very easily found by observation. For example, suppose we know the periodic time of Venus to be two hundred and twenty-four days, and we wish to use the third law to compute its distance from the sun, — using the earth, we have —

$$365\frac{1}{4}^2 : 224^2 : : 93{,}000{,}000^3 : x^3.$$

Having found x^3 we extract its cube root, and the result is the distance required.

So also if we discover a new planet, we have only to observe it until we have found its periodic time, and then apply this third law, which enables us to compute its *approximate* distance, at least, in a few minutes.

Before concluding this *talk*, I have one more point to call to your attention. Perhaps you have already noticed its omission. I have given you the diameters, and volumes of the sun and planets; but I have not said anything about their *masses*. Your books tell you that mass is a different thing from volume. The volume of a body has reference to the cubical contents of the body, or its size. The mass of a body is

the quantity of matter it contains.[1] When we know the volume and mass of a body, we can find its *density*, or *specific gravity*.

You remember that when we attempted to find the distances and diameters of the sun, moon, and planets, our first step was to find the exact dimensions of the earth. Well, before we can calculate the *masses* of the sun, moon, and planets, we must first find the *mass* of the earth.

This calculation depends upon Newton's "Law of Universal Gravitation." It is entirely too abstruse to introduce into these *talks*. To read Newton's "Principia," or Laplace's "Mécanique Céleste," understandingly, requires great knowledge of mathematics. I am only going to try to give you an *idea* of how Newton's law is applied to the determination of the mass and density of the earth.

Newton's law may be thus stated: the force with which two material particles respectively attract each other is directly proportional to their masses, and *inversely* proportional to the square of the distance between their centres.

The density of the earth, or its *specific gravity*, has been determined in three ways: —

[1] Mass must not be confounded with weight. The weight of a body is the apparent force with which it is attracted toward the centre of the earth, and this varies. The weight of a body is greater at the poles than at the equator and is less at high altitudes than at the surface of the earth.

1. By comparing the attractive force of a large metallic ball of known size and density, with that of the earth.

2. By finding how much a large mountain will deflect a plumb-line, or draw it towards itself from the perpendicular.

3. By determining the rate of vibration of the same pendulum on the top and at the bottom of a mountain, or at the bottom of a mine, and at the Earth's surface.

The first method is known as the *Cavendish Experiment*. In Airy's lectures you will find a full explanation of it. It is too difficult to explain here.

In 1772, the English astronomer and mathematician, Maskelyne, proposed to the Royal Society to try the second method. Accordingly, he went in 1774 to a very high mountain called Schehallien, in Perthshire, and there he measured the inclination or deflection of the plumb-line on each side of the mountain. According to the theory of gravitation, — supposing the earth to be an exact sphere, — the lead at the end of the line should point directly toward the centre C of the earth (Fig. 10) if the mountain did not disturb it; and if the plumb-line is taken to two places a certain distance apart and its inclination measured by means of celestial observations, it is easy to find out how much the lines D F, D′ F′, will incline toward

each other when no mountain is between them. This being known, Maskelyne then made two observations, one on each side of Schehallien, and found that in this case the inclination, instead of being from D to F, and from D′ to F′, on each side, was from E to F, and from E′ to F′, because the mountain attracted the lead to-

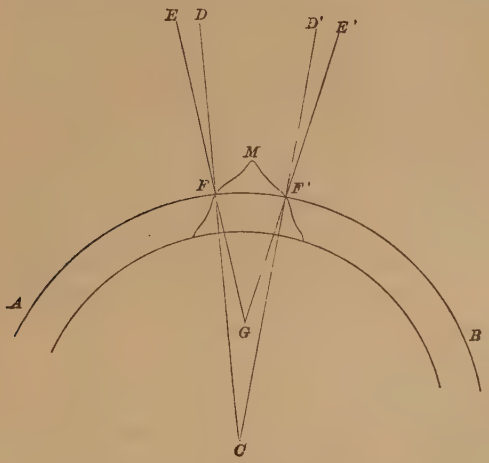

FIG. 10.

ward itself on either side. So the deflection E F D, or E′ F′ D′, through which the plumb-line was drawn from the perpendicular showed the difference between the attraction of the whole earth and the attraction of the mountain. See Fig. 10; A B is the surface of the earth; D C D′ the angle formed by two plumb-lines

pointing to the centre of the earth; and E G E′ the angle formed by the two plumb-lines, when drawn aside by the mountain, M.

Dr. Hutton, the celebrated mathematician, calculated the size and weight of Schehallien.[1] This he did by surveying it and measuring it in every direction, and then taking pieces of the different rocks it contained and weighing them carefully. When this was done it was found that the mountain pulled half as strongly in comparison to its size as the earth did for its size. This showed that the materials in the mountain were half as heavy as the average of those in the earth generally; and as they were also about 2½ times as heavy, bulk for bulk, as water, it was proved that the whole globe is about five times heavier than it would be if it was made entirely of that fluid.

The above illustration is from Buckley's "History of Natural Science." You will find a full explanation of this experiment in "Airy's Lectures," and you will also see how intricate the calculations are. It is sufficient for us to know that the density of the earth as compared to water is as 5.45 to 1. And I will tell you here that the planets increase in density as they approach the sun; Mercury being the densest,

[1] The Encyclopædia Britannica says: "Playfair estimated with greater accuracy the mass of Schehallien, and obtained 4.7 for the earth's mean density.

Venus, the Earth, and Mars about of the same density, Jupiter only one-fifth as dense as the Earth, and Saturn, Uranus, and Neptune still less dense than Jupiter. The density of the sun is one fourth the earth's density.

The earth's density being found, its mass is easily calculated; and knowing the earth's mass, the masses of the sun, moon, and planets have been computed.

Thus we see that a planet revolves about the sun because of the attraction of gravitation. Referring to this Law of Gravitation, the poet Rogers says, —

> "That very law which moulds a tear
> And bids it trickle from its source,
> That law preserves the earth a sphere,
> And guides the planets in their course."

ON THE VELOCITY OF LIGHT.

Mr. Richard Proctor the astronomer says: —

"If light did not travel with a velocity enormously exceeding that of the planets in their orbits, they would seem to move very irregularly, — at least until the cause of the irregularity had been discovered; we should sometimes see Mars, for example, where he was a month or so before, sometimes where he was a year or so before, — *i. e.*, sometimes twenty or thirty millions of miles, sometimes two or three hundreds of millions of miles, from his true place. As it is, light crosses the greatest distance separating us from Mars in about twenty minutes, and the least in about four minutes, so that the irregularity in his apparent motions never amounts to more

than the distance he traverses in about sixteen minutes, or a little more than fourteen thousand miles. If light travelled at the same rate as sound, it would have been absolutely impossible for men to interpret the apparent planetary motions, and the most erroneous ideas would inevitably have prevailed respecting the real motions. Even if the velocity of light had amounted to twenty or thirty miles per second, instead of its real value — about 186,000 miles per second — the true theory of the planetary movements would have seemed absolutely inconsistent with what the eye would have seen. Even as it is, astronomy is directly opposed to the doctrine that 'seeing is believing.' We see every celestial body, not where it is, but where it was. It is hardly necessary to remark that astronomy, in predicting the motions of the celestial bodies, as well as the occurrence of eclipses, transits, occultations, and so on, takes this circumstance fully into account."

TALK THE TENTH.

The Stars, — their Number; Magnitude; Parallax; Distance. Colored Stars. The Constellations. Geography of the Heavens. Use of Globes. The Zodiacal Constellations. Classification of the Stars. The Milky Way. Double Stars. Variable Stars. Star-Clusters. Nebulæ. The Magellanic Clouds. Meteors. Meteorites. Star-Showers. Comets. Star-Dials. Precession. Nutation.

WE have so far talked of the earth, the moon, the sun, the planets, and their satellites; that is, we have confined ourselves to our solar system. Let us now turn our attention to the stars.

You remember I told you in our first *talk* that the early observers soon noticed a difference between the planets and the stars. They found that while the latter were "fixed," the former changed their positions among them. Another thing they probably noticed, — the planets shine with a steady light; the stars "twinkle."

> "And nimbly tumbling out of bed,
> The little stars commence to twinkle."

Campbell, speaking of the approach of night, says, —

> "And sentinel stars set their watch in the sky," —

which very prettily describes the appearance as the stars of the first magnitude first become visible at the approach of night.

The planets shine by reflected light; the stars shine by their own light. Every star is, in fact, a sun, and like the sun an incandescent mass; and each one is probably the centre of a system, and surrounded by planets just as our sun is. The sun is a star; and although to us so large and bright, its size is small compared to some of the stars. Why, it is conjectured by astronomers that if the sun were removed to the mean distance of the first-magnitude stars, it would appear as a star of the sixth magnitude.[1]

The number of stars seems to be unlimited. With the naked eye it is supposed that 6,000 can be seen; that is, 3,000 at any one time. This embraces stars up to the sixth magnitude; but it depends upon a person's eyesight, of course. But with the telescope millions are revealed; and as telescopes are constructed with greater magnifying power, more and more stars are seen. No wonder that Milton says, —

"Innumerable as the stars of night."

With powerful telescopes 20,000,000 are visible, but of course only a fraction of this number

[1] This admits of a doubt, however.

have been catalogued; that is, their right ascensions and declinations calculated.

Still, the German astronomer Argelander has issued a catalogue containing the positions of 324,000 stars. Think what work is involved in this!

There are 20 stars of the first magnitude, 65 of the second, 300 of the third, 450 of the fourth, and so on up to the fourteenth, increasing largely in number as we descend in the scale of brilliancy. You can commit to memory the names of the bright stars in a few minutes; they are, in the order of their brightness, Sirius, Canopus, Alpha Centauri, Arcturus, Rigel, Capella, Vega, Procyon, Betelgeuse, Achernar, Aldebaran, Beta Centauri, Alpha Crucis, Antares, Altair, Spica, Formalhaut, Beta Crucis, Pollux, and Regulus.

But what do we mean by magnitude? Not size, — we know nothing about the size of the stars, — we mean *brilliancy*. The brightest are called stars of the first magnitude; the next, stars of the second magnitude, and so on to the fourteenth magnitude. Of course this rule is approximate, for all stars of the same magnitude are not precisely of the same brilliancy. Sirius, the brightest of all the stars, is nearly three times as bright as the other first-magnitude stars. In the star-catalogues you will see marked against a star, "1. 2." This means that

it is between the first and second magnitude, and so on.

The stars appear as mere *points of light*, even with the most powerful telescopes. We cannot, therefore, determine their angular diameters. The best instruments in the world cannot measure the angle subtended by a star's disk. What follows from this? Why, they must be immensely far off. The sun subtends an appreciable angle (about 33′); yet the stars, although much larger — as we suppose — subtend none.

Can we determine their distance? Let us see how astronomers have tried to do so. You remember the moon's distance was found by measuring its zenith distance, — the two observers being far apart on the surface of the earth, — and thus finding its parallax. Having found its parallax, its distance was easily computed. The distance between the observers was the *base-line* of the operation.

Now, when we use this method with the stars, we can get no result. The parallax cannot be discovered. I will repeat that the parallax we are trying to find is the angle subtended at the star by the distance between the two observers; or it is the difference in the apparent direction of the star, as seen by the two observers. But it matters not how far apart the observers may be placed, — even if one were at the north pole,

and the other at the south pole, — the stars are always seen *in the same direction;* that is, no parallax is discovered.

This method will not do, then. It answers for the moon, which is only 240,000 miles off, but it will not do for the stars. Indeed, we have seen that it will not do for the sun; and the sun is *much nearer* to us than the nearest star, though *it* is 93,000,000 miles off. The *base-line* is evidently too small. Can we find a longer one? Yes; as the earth moves half-way in its orbit in six months, we may use the diameter of the orbit itself as a base; that is, a base-line 185,000,000 miles long. We have certainly increased our base-line very much. What is the result? Surely, now, we must find some parallax! No; wonderful to say, although we have moved 185,000,000 miles, the stars appear still in the same direction.[1] Does not this convey to the mind the idea of immense distance?

Light travels, as we have seen, about 186,000 miles a second; and it is *conjectured* by astronomers that if a star of the sixth magnitude were destroyed, we should continue to see it in the heavens for 120 years; and if one of the twelfth magnitude were now created, it would be 3,500 years before its light would reach the earth.

Bessel, the great German astronomer, by a method which I need not explain here, did,

[1] Or at least the change is so small that it can be detected in only a few cases, and then only by the most delicate observations.

however, discover the parallax of the small star, 61 Cygni; and by his method the parallax and distance of forty-six stars have been found. The nearest star is Alpha Centauri; and when I tell you its parallax is but *seven tenths of a second* (of arc) you will comprehend the extreme difficulty of the problem. From the parallax of Alpha Centauri its distance has been computed. It is found to be 224,000 times the distance of the sun, — that is, 93,000,000 multiplied by 224,000; these figures are so great that the mind fails to grasp them.

As the stars are of different degrees of brightness, so are they of different colors. Most of them appear white, but a few shine with another light. Thus, Aldebaran and Antares are red; Vega, Spica, and a few others blue; Sirius, Altair, and two others green; [1] and Arcturus and Capella yellow. With the exception of the red stars, however, they appear generally white; and, so far as the color is concerned, they all look alike. How, then, do we distinguish them?

If I were walking with one of you on a cloudy night, and a single star should peep out between the clouds, and you should ask me what star it was, I would answer that I did not know. I might say it looked like a star of the

[1] Professor Lockyer says this; but I have never noticed a greenish hue myself, and to me Spica appears red.

first magnitude; or, if very bright, that it might be Sirius; or, if red, that it might be Aldebaran, or Antares; but I could not say positively what star it was. How could I when they all, or nearly all, look alike? I should be inclined to quote Sancho Panza, and say: "In the night all cats are gray."

Now, you know a sailor determines his position at sea by what he calls his "bearings." Well, it is just so that we find a particular star in the heavens; we see how it bears from certain other stars. (I am speaking of an observer viewing the heavens with the naked eye. Astronomers, in their observatories, can find any star by its right ascension and declination; and indeed, as they generally use stars of the fifth or sixth magnitude in their observations, some of them do not know the bright stars when they see them. They do not pay much attention to what we call the geography of the heavens).

It is for this reason astronomers have grouped the stars under the name of "constellations." I do not refer to the figures of lions, bears, dragons, etc., found on celestial maps. No mortal man could ever trace them out, and astronomers pay no attention to them. But there are some which present figures plain enough to distinguish, and by these constellations we find the stars. There are one hundred and nine of these groups. Some of them re-

ceived their names fifteen hundred years before the Christian era; and all the principal ones were known before Christ. Some of the brightest stars are still called by the Arabian or other names by which they were formerly known: Thus, *Alpha Canis Majoris* is called Sirius; *Alpha Boötis*, Arcturus; *Alpha Tauri*, Aldebaran; *Alpha Ursæ Minoris*, Polaris, or the pole star, etc.

The constellation which you should all be able to point out is *Ursa Major*, the great bear; because by the arrangement of seven stars in it we can find the pole or north star. These seven stars form a "dipper," and two stars in it, called the "pointers," always point to the pole star, which star is in *Ursa Minor*, the little bear. If you do not know the pole star, get some one to show you how to find it by the "pointers," without loss of time. Every one should know how to find the pole star, at least. Again, the three bright stars in the belt of Orion point to Sirius; Aldebaran is in the leg of a V-shaped constellation, etc.; and, as I said in our first *talk*, as the stars are "fixed," these figures or constellations are unchangeable in form. The "dipper," in our latitude (say 40° N.) revolves about the pole star, and is always above the horizon. Although we see it, sometimes to the right of the pole star, and at others to the left, — sometimes above it, and

again below it, — at times right side up, and at others inverted; yet it always preserves the figure of a "dipper," and the "pointers" point steadily to the pole star.

It is a very interesting study to observe the heavens at night, and to be able to point out the stars and constellations, and give their names; but you must not imagine this to be *Astronomy;* as I fear it is too often supposed to be. If, in your study of geography, your teacher had required you to simply learn the *names* of the cities and countries of the world and say: Berlin is in Prussia, Lima is in Peru, Chimborazo is in Ecuador, etc., you would not know much geography, would you? You would wish to know something about the structure of the earth, the manners and customs of the inhabitants, and many other things. Well, so it is with the geography of the heavens and astronomy. It is all very well to know the names of the stars and how to find them; but *astronomy* tells us of the motions, distances, dimensions, physical constitution, etc., of the heavenly bodies.

I do not know whether the "globes," and their use, is generally taught in our schools. In England their use in young ladies' seminaries is, I believe, universal. I think it was Thackeray who said he doubted if any young lady ever

really did learn the "use of the globes." I will not be as cynical as that, because I have not much used the "globes" myself, and am not qualified to say to what extent they assist the student to comprehend astronomical problems. All minds differ. Some of you in your mathematical course liked algebra, others preferred geometry; some like to get at the truth by abstract reasoning, others want a graphic illustration. In the study of astronomy, then, if you find you can better *think it out*, do so (it is by far the best way); if you find you can do better with a diagram, draw it; and if you find that an orrery, or a globe, or a celestial map, assists you, use it.

Perhaps you all know the zodiacal constellations, as they are called. You see frequent mention of them in your books. What are they called for? The zodiac.

The zodiac is a portion of the heavens, extending nine degrees on either side of the ecliptic, in which the sun and major planets appear to perform their annual revolutions. The twelve constellations through which the sun passes in his annual round, are called the zodiacal constellations. Their names are: *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, and *Pisces*.

The zodiacal constellations must not be confounded with the *Signs of the Zodiac.* The point where the sun crosses the equator at the vernal equinox (March 21), that is, at the intersection of the ecliptic and the equator, was, in the time of Hipparchus, — 2,000 years ago, — in the constellation *Aries,* and it was called the first point of Aries.

At that time the sun was in *Aries* at the vernal, and in *Libra* at the antumnal equinox. Owing to what is called the *precession of the equinoxes* (which I will tell you about presently), the sun is now in *Pisces* at the vernal, and in *Virgo* at the autumnal equinox; and it is constantly changing, though very, very slowly.

What stars are mentioned in the Old Testament? The *Pleiades*, *Arcturus*, and *Orion.*

Canst thou bind the sweet influences of Pleiades, or loose the bands of Orion? — *Job.*

Which maketh Arcturus, Orion, and Pleiades. — *Job.*

Having seen how astronomers group the stars into constellations, let us now inquire into the manner of classifying and naming them. The method now in use, introduced by Bayer of Augsburg, in 1603, is to arrange all the stars in each constellation in the order of brightness, and to attach to them, in that order, the letters of the Greek alphabet, using, after the letters,

the genitive of the Latin name of the constellation. Thus: *Alpha Lyræ* denotes the brightest star in the Lyre; *Beta Centauri*, the next to the brightest in the Centaur, and so on. After the Greek alphabet is exhausted, the Roman alphabet is used in the same way; and after that, recourse is had to numbers. Thus: 61 Cygni is a very small star in the Swan.

The milky way, — *Via Lactea*, — sometimes called the galaxy, — which you cannot fail to have observed, is composed of stars so faint and apparently so near together that the eye can perceive only a dim, continuous glimmer. This causes the *whitish* appearance. Thus Sir John Suckling says, —

> "Her face is like the milky way i' the sky,
> A meeting of gentle lights without a name."

With powerful telescopes astronomers discern double-stars, variable stars, star-clusters, and *nebulæ*. The term *nebula* was formerly applied to everything in the sky which appeared cloud-like to the naked eye or in a telescope. Now, a *nebula* is supposed to be a mass of self-luminous gas. It is foreign to my purpose to say anything here concerning what is called the *nebular hypothesis*, save only that it is a *speculation* as to how the stars, planets, and satellites were first formed.

When Magellan got pretty far south on his voyage around the world in 1519, he observed two cloudy oval masses of light, which have since been called the Magellanic Clouds. They look very much like *cirrus* clouds, — but Magellan must have soon noticed that they were not clouds, from the fact that they did not move with the wind, but preserved their relative positions to the stars; moreover, they appeared night after night. These clouds are said by astronomers to be star-clusters, and nebulous matter in various degrees of condensation.

Now let me say something about two other heavenly bodies, not yet mentioned by me, — *meteors* and *comets*.

We frequently see at night what we call shooting stars. They are what astronomers call meteors. These small bodies are opaque, and travel around the sun. Sometimes the earth in its orbit passes through them, and we have a star-shower. These showers may be expected to occur in the months of August and November. The most famous one of which we have any account occurred in this country in November, 1833.

But if these bodies are opaque, how is it that they emit such a bright light? It is owing to the fact that they enter our atmosphere at the velocity of about thirty miles a second, and the

friction sets them on fire. Most of them are entirely consumed; but occasionally one is found large enough to resist the action of the atmosphere, and falls to the earth. This is called a *meteorite.* They are divided into three classes to indicate their structure; they are stone, iron, or intervening varieties.

When we go back to the records we find that a large number of meteorites are known to have fallen. Some have killed men and cattle, and buildings have been set on fire by them. They have been known to fall in showers; and, indeed, I read of such a shower happening in the Argentine Republic only a few years ago. In a case of the kind one would be likely to "come in out of the rain," without waiting to be told. You will find specimens of meteorites in most museums.

We occasionally see in the heavens luminous masses called comets, which shine by their own light. They circle around the sun in a variety of orbits; some of them are ellipses, some parabolas, and some hyperbolas. Some move from west to east (as the planets do), and others from east to west. The comets having elliptical orbits return again to our system, and their periods have been calculated; those whose orbits are parabolic or hyperbolic never return.

Of what are these eccentric bodies composed? There is first, the head, or *coma;* in the head (sometimes) a bright spot like a star, called the *nucleus;* and lastly, the tail. The *nucleus* is the brightest, then the *coma*, and then the tail. The tail is sometimes millions of miles long.

What do we know of their physical constitution? In the case of a comet without a *nucleus*, the *coma* is probably a mass of white-hot gas. The tail is even lighter, and may be regarded as the waste, so to speak, of the *coma.* Stars can be seen through both the *coma* and the tail. What the *nucleus* is, we do not know.[1]

Comets are very eccentric in their movements. Sometimes they move towards the sun, at others away from it; and sometimes they appear to be coming head-first for the earth. In former days this gave rise to great apprehensions.

You may recollect that Stephenson was the inventor of locomotives and railroads. Someone objected that a locomotive might come into collision with a cow. "So much the worse for the coo," replied Stephenson, in his broad

[1] Professor Keeler, of the Lick Observatory, says that carbon seems to be a constituent of most comets, and that some comets probably have dense nuclei of considerable magnitude.

Scotch. Well, so it would be with a comet if it should come in collision with the earth. It weighs but a few ounces at most, and it could not possibly hurt the earth.

How do we know it weighs so little? Because in 1776 a comet passed between Jupiter and its satellites. These satellites are small bodies, yet they were not at all disturbed in their orbits by the attraction of gravitation of the comet, while the comet, itself, was thrown entirely out of its course.[1]

While on this subject of comets and meteors, I must tell you I have given you the theory in relation to them that is generally accepted. We, doubtless, have much to learn concerning comets; and as to the origin of meteors, there are not wanting highly scientific men who believe they were actually ejected into space by the volcanoes of the earth, in ages past.[2] They are probably of volcanic origin.

One remark more, and I have done with the stars. You know that people in the country who are without clocks can tell the time of day pretty well by the position of the sun. In former days, when clocks were rare and expensive, most persons in the country had a "sun-mark," — that is, the shadow cast by the sun when on the meridian was marked so as to indicate noon.

Now persons whose occupations keep them

[1] By the attraction of Jupiter.

[2] This is a mere speculation of course.

up at night, can judge of the time by the stars pretty accurately. Thus Poe says, —

"And star-dials pointed to morn."

In early times the "dipper" was the constellation most frequently observed, to judge of the time.[1] As I have told you, it is always visible to us. When I say this, I do not mean we see it in the day-time with the naked eye, — you know we do not, — but you must understand that in a telescope the stars can be seen in the day-time as well as in the night.

The "dipper," or "seven stars," as some call it, moving round the pole, occupies all varieties of positions, as we have seen; and it was naturally used to denote the hour of night. Thus, in "Henry IV.," Falstaff says, —

"We that take purses go by the moon and seven stars."

Now, the *Pleiades* are also called the seven stars, and Falstaff *may* have alluded to them; but I think he meant the "dipper," for in the same play the Carrier says, —

"An' it be not four by the day, I 'll be hanged;
Charles's Wain is over the new chimney!"

The "dipper" is sometimes called "Charles's Wain," in England, at the present day. It is from the Scandinavian *Karlsvagn*, — the Carle's

[1] In northern latitudes, of course.

Wain. It is called, also, "the wagon," from the Icelandic, *Stori* (great) *Vagn.*

I said a few pages back I would explain what is meant by the *precession of the equinoxes.* I spoke of the *effect*, which is that the point of intersection of the ecliptic with the equator, — that is, the *equinox*, — moves backward *very slowly* and, as it were, meets the sun. Two thousand years ago this point was in the constellation *Aries*, and now it is in *Pisces.* I called your attention to the fact that the *signs of the Zodiac* no longer corresponded with the Zodiacal constellations, and must not be confounded with them.

If the earth were a perfect sphere, there would be no precession; but it is an oblate spheroid, and the attractions of the sun and moon on the equatorial regions cause the pole of the equator to describe a very small circle round the pole of the ecliptic. Hence, though I have spoken of the earth's axis always pointing in the same direction, it is not *strictly* true. The pole of the earth revolves about the pole of the ecliptic once in about 25,868 years.

Astronomers have calculated that 4,500 years ago the pole-star was *Alpha Draconis*, and in about 12,000 years the pole-star will be the bright star *Alpha Lyræ;* and although we are now nearer the sun in January, at one time we

were nearer it in June, and in the course of time will be again.

The motion of precession is not uniform, owing to the varying attraction of the moon. This causes the pole to revolve in a wavy curve, and is called *nutation*.

TALK THE ELEVENTH.

Time. Its Measurement. Standard of Time. Apparent Solar Day. Sidereal Day. Mean Solar Day. Equation of Time. Mean Time and Apparent Time. The Civil Day. The Astronomical Day. Lunar Day. Sidereal Time. Clepsydræ. Sun-Dial. Clocks and Chronometers. The Week. The Month. Lunar Month. Sidereal Month. Calendar Month. Tropical Month. Anomalistic Month. Nodical Month. The Year. Sidereal Year. Tropical Year. Anomalistic Year. Absolute and Relative Time. Local Time. Standard Time.

THE subject of our next *talk* will be Time; and you will be surprised when I tell you that most persons know very little about it. I do not wonder at that myself, for in my experience as a teacher at the U. S. Naval Academy and other colleges, I found this very subject of Time the most difficult one for the student to comprehend. And yet it seems a very simple matter.

The exact measurement of time is one of the most important parts of practical astronomy. Let us see how we attempt to compass it.

The natural standard of time is one revolution of the earth upon its axis. What we have to do,

then, is to determine this period. We naturally turn to the sun to discover it. We are met with a difficulty at the beginning; and that is, that the intervals between the successive arrivals of the sun upon the same meridian are constantly changing.

Now, as we cannot suppose the earth's motion on its axis to be irregular, we turn our attention to another celestial object, and see if the result is the same. We next, then, observe the moon; the same irregularity in the intervals occurs. We then try the planets, and the result is the same. Lastly, we observe the stars, and the difficulty is solved. They, one and all, give *always* the same interval, and it never varies. The interval is 23 hrs., 56 min., 4 sec. All the stars give this result, and you know there are millions of them. The earth, then, makes one revolution upon its axis in 23 hrs., 56 min., 4 sec.

Let us now look back and see why the sun gives irregular intervals. It is because the earth is moving around it. If the earth stood still in its orbit, the intervals would always be the same, and they would be the same as that given by the stars; but owing to its yearly motion, the obliquity of the ecliptic, and the fact of its moving faster when in *perihelion* than when in *aphelion*, the intervals between the times of its meridian passage vary, as I have said.

In the case of the moon and planets, the reason is plain why *they* give irregular intervals; they have a motion of their own around the sun. And the moon, furthermore, revolves about the earth. The stars give always the same interval, because they are "fixed."

Here, then, we have three days: the Apparent Solar Day (variable), the Apparent Lunar Day (variable), and the Sidereal Day (constant).

Now the sun giving us what we call day and night, we must use it to determine our time. But no instrument, from a clepsydra to a clock, can be constructed to keep *irregular* intervals from twelve o'clock one day to twelve o'clock of the next. This is evident. What, then, do we do? Astronomers imagine what is called a mean sun, and suppose the revolution of the earth upon its axis to be performed in just twenty-four hours, and this is what we call a mean solar day.

This is the time kept by our clocks and watches, and is our ordinary time; that is, what is called *mean time*. A sun-dial shows the time by the true sun, and this time is called *apparent time*. The mean time is sometimes ahead of the apparent time, and sometimes behind it; but four times in the year, about April 15, June 15, September 1, and December 24, the two times exactly agree. The difference between the apparent time and the mean time is called

the Equation of Time. It is never greater than about sixteen minutes. The apparent time can be changed to mean time by applying this "correction," and *vice versa*. The equation of time is given in the nautical almanac for every day of the year; it is sometimes additive to the apparent time, and sometimes subtractive.

But remember that the "time by the sun" is always apparent time. When we observe with an instrument the sun on the meridian it is twelve o'clock *apparent* time. If we calculate the time by observing the sun's altitude (which we do daily at sea, as I shall tell you of presently), it is the apparent time we find; and the apparent time is the same thing as the sun's hour angle if the hour is P. M., — because it is the number of hours from the meridian, or noon. If the hour is A. M., the apparent time subtracted from twelve, gives us the sun's hour angle.[1]

Mean time is the time kept by our clocks and watches, and is the time we allude to in daily life. When the *mean* sun is on the meridian it is twelve o'clock mean time; and our clocks and watches, if correct, indicate it.

This mean solar day of twenty-four hours is called the Civil Day, and it commences at midnight. It is reckoned through twelve hours,

[1] If we count our hour angle around the circle, the sun's hour angle is the apparent time.

only, to noon, and thence through another twelve hours to midnight, — and it is marked A. M. and P. M., as you know.[1]

Astronomers in their computations suppose the day to commence at noon, twelve hours after the commencement of the civil day; and this is called the Astronomical Day. It is probable this will be discontinued in a few years, and the civil day substituted.

Now we have seen that the moon gives us irregular intervals for a day. A lunar day is longer than a solar day, as it should be; for the moon moves to the *eastward* while the earth is moving also from west to east. Hence it takes the earth more than twenty-four hours to "catch it up," as it were, and bring it upon the same meridian again. The mean lunar day is twenty-four hours, fifty-one minutes long. You see now why it is that the moon rises about fifty-four minutes later every night; and, also, why the flood tide makes about fifty-four minutes later from day to day.

[1] S. Grant Oliphant says: "We have sixty divisions on the dials of our clocks and watches because the old Greek astronomer Hipparchus, who lived in the second century before Christ, accepted the Babylonian system of reckoning time — that system being sexagesimal. The Babylonians were acquainted with the decimal system, but for common or practical purposes they counted by *sossi* and *savi*, the *sossos* representing sixty and the *savos* sixty times six — three hundred and sixty.

The sidereal day is always the same. We have, therefore, no mean sidereal day. In ordinary life we have no use for sidereal time; indeed, perhaps there are but few persons who know anything about it. But astronomers use it in their observatories. The hours on the face of a sidereal clock are marked up to twenty-four; and it shows 0 hours 0 minutes 0 seconds when the vernal equinox, or a star whose right ascension is 0 hours 0 minutes 0 seconds, is on the meridian. We can change solar into sidereal time, and *vice versa*.

As the sidereal day is shorter by about four minutes than the mean solar day, it follows that the stars rise four minutes *earlier* every night.[1] The consequence of this is that in the course of a year we see all the stars visible at our place of observation. Since a star rises four minutes earlier daily, in a month of thirty days it will have gained one hundred and twenty minutes, or two hours, — that is it will rise two hours earlier. In six months it will have gained twelve hours, — so that a star which was rising, say at sunset, will in six months be just setting; while the star that was setting at that time will be rising. Thus you see that in the following six months we shall have an entirely new set of stars above the horizon at night. You see that if the sidereal day was of the same length exactly as the

[1] See note, page 179.

mean solar day, the same stars would be visible every night; one half of them would be above the horizon at night, and the other half in the daytime, and the latter would be visible only in a telescope. Of course this does not apply to the circum-polar stars, which you know do not set; but are always above the horizon. The constellation of the Great Bear, or "Dipper," is an example.

For the measurement of time the ancients used *clepsydræ*, and sun-dials. The *clepsydræ* were, as the name denotes, water-clocks. That is, the intervals of time were measured by the flow of water. If we take an ordinary hour-glass and fill it with water instead of sand, it will represent a *clepsydra*. When in use they were constructed of various forms, — all depending, however, upon the flow of water, — and were made ornamental as well as useful; just as our parlor clocks are at the present time. Suppose we should make a rectangular box, fill it with water, and then bore a small hole in the bottom to allow the water to escape. Now, we could see how much water ran out in one hour, and could mark the box by drawing a horizontal line; then, supposing the box to be in exact proportion, twelve of these horizontal lines represent twelve hours. The box would have to be filled with water at the

end of that time, just as we have to wind up our clocks and watches.

I have seen a drawing of a *clepsydra* which represented the figure of a man standing upon a flat piece of wood, floating on the top of water in a box. The man was in armor, and held a drawn sword in his right hand. The point of the sword rested on a perpendicular dial, upon which were marked the numbers from one to twelve. When the box was full of water, the sword pointed to twelve; in the course of an hour, the water having fallen, the sword pointed to one, and so on. You see, then, the construction admits of a variety of forms.

But you will naturally ask me how these marks were determined. As the ancients had no clocks, how did they know the interval we call an hour? Well, *they did not know it.* They called the time from sunrise to sunset 12 hours, and marked their *clepsydræ* accordingly. It followed from this that as the days in the summer are longer than in winter their hours were of different lengths; and the winter *clepsydræ* would not answer for summer, and *vice versa.* In fact, except for measuring intervals of time, they were very inaccurate, unless different ones were used at different seasons of the year.

The sun-dial was used by the Jews as long ago as 742 B. C. It was a great improvement

on the *clepsydra;* but, you know, in cloudy weather and at night it is useless. The construction of a sun-dial is very simple; it consists of a *style* and a *dial.* The style is a rod, set parallel to the earth's axis, and its shadow is thrown upon the dial, which latter is marked to indicate the hours. You will find frequent reference to the sun-dial in Shakspeare, and other old poets; and if you ever visit the Spanish countries of this continent, you will find in every town of importance a sun-dial, which was placed there by the Conquerors. One of the most interesting objects in the town of Acapulco, Mexico, is the old sun-dial in the *plaza.*

Mr. Lockyer says: "Clocks appear to have been first used in Europe in the eleventh century; and the first clock made in England was in 1288." [1]

[1] Shakspeare says, —

> "And then he drew a dial from his poke,
> And looking on it with lack-lustre eye,
> Says, very wisely, 'It is ten o'clock.' "

Bulwer says: "Clockwork appears to have been introduced into England in the reign of Edward III. [1327–77], when three Dutch horologers were invited over from Delft. They must soon have passed into common use, for Chaucer [1320-1400] thus familiarly speaks of them: —

> "'Full sickerer was his crowing in his loge,
> Than is a clock or any abbey orloge.' "
>
> *Chambers's Encl.*

Now, both clocks and watches are in use all over the civilized world, and are sold so cheap that we rarely find a house without one. The sidereal clock used in observatories, and the chronometer used by navigators are made with great care, and are still expensive instruments. I will tell you something about chronometers, and their use, in another place.

The *week*,[1] unlike the day, month, and year, is not connected with the movement of any heavenly body. Mr. Lockyer says the names of the seven days of the week were derived by the Egyptians from the seven celestial bodies then known; and that the Romans, in their names for the days, observed the same order, distinguishing them as follows,—

Dies Saturni,	Saturn's Day,	Saturday.
Dies Solis,	Sun's Day,	Sunday.
Dies Lunæ,	Moon's Day,	Monday.
Dies Martis,	Mars's Day,	Tuesday.
Dies Mercurii,	Mercury's Day,	Wednesday.
Dies Jovis,	Jupiter's Day,	Thursday.
Dies Veneris,	Venus's Day,	Friday.

We see at once the origin of our English names for the first three days; the remaining

[1] I think it likely that the ancients were led to this division of time by counting from new moon to first quarter (and so on) of the moon. They divided the lunar month into four parts; but this is only a supposition.

four (Mr. Lockyer says) are named from *Tiw*, *Woden*, *Thor*, and *Frigga*, Northern deities equivalent to Mars, Mercury, Jupiter, and Venus, in the classical mythology.

The *month* is a period regulated entirely by the moon's motion around the earth. The *lunar month* is reckoned from new moon to new moon; its length is about 29 days, 12 hours. The *sidereal month* is the interval between two successive conjunctions of the moon with the same fixed star; it is, in fact, the exact time it takes the moon to make one revolution about the earth. Its length is 27 days, 9 hours.

The *calendar month* is the month recognized in the almanacs; such as January, February, March, etc. You know the number of days in each of these months.

Astronomers speak also of the *tropical month*,[1] the *anomalistic month*, and the *nodical month;* but I need not dwell upon these distinctions here.

We next come to the *year*. This is the time of the earth's revolution about the sun. There

[1] The tropical month is the revolution of the moon with respect to the movable equinox. The anomalistic month is the time in which the moon returns to the same point — such as the perigee or apogee — of her movable elliptic orbit. The nodical month is the time in which the moon accomplishes a revolution with respect to her nodes, the line of which is also movable.

are various years, just as there are different kinds of days and months.

The time that elapses between two successive conjunctions of the sun (as seen from the earth) with a fixed star, is called a *sidereal year;* its length is 365 days, 6 hrs. 9 min. 9.6 sec., — and this is the exact time of the earth's revolution about the sun.[1]

The time that elapses between two successive passages of the sun through the vernal equinox, is called the *solar*, or the *tropical year*. Its length is 365 days, 5 hrs. 48 min. 46 sec. It is rather less than the *sidereal year*, because the equinox has moved a little to the westward, and the sun reaches it a few minutes before it reaches the star. This movement is known as the *precession of the equinox*, as I have said.

If we consider the time it takes the earth to move from *perihelion* to *perihelion* again, we have still another year; it is called the *anomalistic year*. Its length is 365 days, 6 hrs. 13 min. 4.9 sec. It is about 4 minutes longer than the *sidereal year*, because these points (*aphelion* and *perihelion*) have a slight forward or easterly motion, and it takes the sun a little longer to

[1] That is, *reckoned in solar time*. It should be observed that in 365 solar days the earth revolves upon its axis 366 times. We have seen that the stars gain about 4 minutes a day. Roughly, we have 4 minutes multiplied by 365 = 1,460 minutes = 24 hours; so 365 solar days equal 366 sidereal days.

reach them. The line joining the *aphelion* and *perihelion* points is called the line of *apsides*.

But the year we are interested in is the solar or tropical year, because on it depends the change of the seasons; and we may disregard the sidereal and anomalistic years. When I speak of a year hereafter, I mean the solar or tropical year.

Having once determined the exact length of the year, astronomers were enabled to correct the calendar, as I explained to you in our first *talk*.

Time, then, is regulated by the sun. When the real sun is on the meridian of any place it is twelve o'clock, *apparent* time, at that place; and a sun-dial will indicate twelve hours. When the *mean* sun is on the meridian of any place it is twelve o'clock, *mean* time, at the place; and our watches and clocks indicate it. You see it is twelve o'clock at every place on the earth's surface when the sun is on the meridian of that place. But the sun must cross the meridian of all these places at a *different time*. How, then, can it always be twelve o'clock? I must explain this, as it leads up to the difference between *absolute* time and *relative* time, which I wish you clearly to comprehend.

Let us take Greenwich, which, as we are in about 75° west longitude, is five hours ahead of

us in *absolute* time. As the earth turns upon its axis, or moves 360°, in twenty-four hours, it must move 15° in one hour; and as it turns from west to east, the *absolute* time of a place east of us, as Greenwich, must be faster than ours, or in advance of ours. Now as we are in longitude 75° west of Greenwich, the time at Greenwich is five hours in advance of ours. The longitude of a place is simply the difference between its time, and the time at Greenwich, reckoning longitude from that place; so if I say we are five hours from Greenwich, it conveys the idea that we are in longitude 75°. If I say our time is five hours *faster* than Greenwich time, I indicate that the longitude is 75° east; and if I say our time is five hours *behind* Greenwich time, I indicate that the longitude is 75° west.

Now the sun crosses the meridian of Greenwich at twelve o'clock, and it crosses our meridian at twelve o'clock; the *relative* times are the same; but in *absolute* time, the sun crosses the meridian of Greenwich five hours before it does ours. When it is twelve o'clock local time at Greenwich, it is 7 A. M. here by our local time. When it is twelve o'clock here by our local time, it is 5 P. M. at Greenwich by its local time.

Every place has its own *local* time; and when the mean sun is on the meridian of any place, the clocks mark twelve hours at that place. This comes from a law of Nature, — the earth

in its revolution must bring the meridian of every place under the sun, once in twenty-four hours; and this moment we have agreed to call twelve o'clock, and it is the *natural* initial point of our day (meaning, of course, twenty-four hours).

Let me give you another illustration to show the difference between absolute and relative time. The time of the sun's rising at any place depends upon the latitude of the place, and the sun's declination. We can construct a table by assuming all latitudes from 0° to 90°, and all declinations from 0° to 23½°, and calculating the time of sunrise for every degree of latitude, and every degree of declination. Such a table is inserted in our books on navigation, and the navigator has only to enter it with his latitude and the declination of the sun to find the hour of sunrise. It saves him the trouble of computing it. The time found is the apparent time; and as the navigator at sea keeps apparent time, it suits him as it is. If we, here on shore, find this time, we apply the equation of time to it, and we have the mean local time of sunrise.[1]

The sun rises at the same hour to every observer on the surface of the earth in the same latitude.

[1] Knowing the time of the sun's rising, we have of course the time of its setting; it is twelve hours *minus* the time of rising (that is, if we keep *local* time).

For example: Gibraltar is in about the same latitude as Norfolk, but the difference of longitude is about 70°; that is, the difference of time is 4 hrs. 40 min. Now on, say the 1st of May the sun rises at Norfolk at 6.45 A.M., apparent time. It rises also at Gibraltar at 6.45 A.M., apparent time. That is, the *relative* times are the same; but in *absolute* time the sun rises 4 hrs. 40 min. sooner at Gibraltar than at Norfolk.

I have dwelt upon this subject of time for the reason that in 1884–85 a change was made in the United States in its reckoning. We have discarded "local" time, and have decided to use the time of some other meridian. We call it "Standard" time. Thus, all places between the meridians of 67½° and 82½° (that is, between the longitudes 67° 30′, and 82° 30′), use the time of the 75th meridian, — the mean meridian between them; all places between 82½° and 97½° use the time of the 90th meridian; and so on.[1]

[1] Professor A. Hall, of the U. S. Naval Observatory, Washington, wrote me in relation to the adoption of "standard time:" "I believe it will lead to all manner of absurdities."

I find the following despatch in the "Baltimore Sun" of Feb. 22, 1889: —

BELLAIRE, O., Feb. 21. — The question of time in Bellaire has been unsettled for some time. The Board of Education has been running the clock in the tower of the Central School building on Eastern standard time. The council wanted sun time, and finding the board would not change, passed an ordi-

I believe we have made a mistake in adopting this rule, for the reason that we are *legislating against a natural law.* I think the time at a place should be indicated by the sun's passage across the meridian of that place, which, as I have before said, is the initial point of the day.

I believe, moreover, we are confusing a subject already sufficiently complicated. Let us consider a few points.

I see by the atlas that a place called Lancaster, in Ohio, is in about the longitude 82° 30′ W. from Greenwich. If the main street of that town runs north and south, and if the centre of that street is in exactly 82° 30′ west longitude (as it may be), a man changes his time one hour by simply crossing the street. The citizens east of the street keep the time of the 75th meridian, and those west of it the time of the 90th meridian, which times differ one hour. And whether this meridian of 82½° runs through a town or

nance making it an offence for any person to expose a timepiece in any public place showing any other than meridian time. Then the war began, and legal counsel was secured by both sides.

Meanwhile the people were divided on the question; some using one time, some another, and others still going by railroad time. To-day the matter culminated in the arrest of M. Hoffman, Wm. Burgenthal, James T. Kelly, and G. W. Yost, members of the Board of Education, — the other two members escaping, as they had become reconciled to sun time. The case is set for Monday, and an interesting fight is promised.

not, there must be places within a short distance of each other whose times differ one hour if the rule is adhered to.

Again, suppose a man in longitude 82°, 29′, 30″, looks in the table to find the time of sunrise on the 21st of March. He finds that the sun rises at 6 A. M. and sets at 6 P. M.; but according to his clock, which is set to the time of the 75th meridian, the sun rises at 6.30 A. M. and sets at 6.30 P. M. That is, it rises 5½ hours before noon, and sets 6½ hours after noon. Will he not find it difficult to explain to his children this anomaly?

I could give many more examples of the kind; but as the adoption of the time is *un fait accompli*, perhaps I have said enough. My object in introducing it is to induce you to *think* of the matter.[1]

We frequently see in the papers a notice of the running time of a steamer between Liverpool and New York. Liverpool is in longitude 3° west, and New York in longitude 74° west. The difference of longitude is 71°, and the difference of time is 4 hrs., 44 min. Suppose a steamer to leave Liverpool on Monday at noon

[1] Since writing this I see in the "San Francisco Bulletin" the following: "Standard time is being abandoned in some Michigan cities and towns, and it is thought the Legislature of that State will repeal the law that legalized its adoption."

(local time), and to arrive at New York the following Monday at noon (local time). Her running time would not be seven days. It would be 7 days, 4 hrs., 44 min., because when it is noon at New York, it is 4 hrs., 44 min. past noon at Liverpool.

Again, suppose a steamer to leave New York on Monday at noon, and to arrive at Liverpool the following Monday at noon. Her running time would be 6 days, 19 hrs., 16 min., because when it is noon at Liverpool, it is 7 hrs., 16 min. A. M. at New York. In the first case, as the steamer goes westward or *from* the sun, her days are longer than twenty-four hours; in the second case, going eastward she *meets* the sun, and her days are less than twenty-four hours.

The papers are accustomed to call this corrected time the steamer's *mean* running time. It is not the mean running time at all. It is the exact time in which she has crossed the ocean in days of twenty-four hours long.

TALK THE TWELFTH.

International Conference held at Washington for the Adoption of a single Prime Meridian and a Universal Hour, October, 1884. Explanation of the Method by which Navigators adjust their Time when circumnavigating the Globe.

IN 1884, at an International Conference held at Washington to decide upon the adoption of one "prime meridian" for the world, one of the subjects discussed was the propriety of adopting one "time" for all nations. This Congress was called by the President of the United States, and twenty-six countries were represented. Among the delegates were the Directors of the Observatories of Washington, Cambridge (England), Paris, Rio de Janeiro, and Mexico; and distinguished astronomers and hydrographers from all parts of the world. The following proposition was adopted: —

"The Conference proposes the adoption of a universal hour for all the uses for which it may be found convenient, and which will not prevent the use of the local hour or any other normal hour which may seem to be desirable."

And also this: —

"The universal day should be a mean solar day. It should commence, for the entire world, at the beginning of mean midnight at the first meridian [Greenwich], agreeing with the commencement of the civil day and the date of this meridian, and it should be counted from 0 to 24 hours."

I think it would have been better to have confined this discussion to the observatories of the world. Astronomers understand this subject of time, and can readily come to an agreement as to a universal day and hour. The world generally know little about it. An attempt to introduce it and to have two dials on our clocks, as some propose, will, I believe, lead to endless vexation, if not confusion.

All change is not necessarily progress. Although a little in advance of my subject (for I intend to tell you a good deal about longitude), I will say something as to the action of this Congress on the adoption of one prime meridian for all nations.

You know we reckon our longitude from Greenwich; and, indeed, it was stated in the Conference that seven tenths of the nations of the earth reckon longitude from the same meridian. France reckons from Paris, Spain from Madrid, Brazil from Rio de Janeiro; and a few other countries reckon from their capital cities.

It is a mere arbitrary rule; we can reckon longitude from any meridian we choose to select. *We* naturally took the meridian of Greenwich, where there is one of the best and oldest observatories in the world. We use English charts and it is convenient to reckon our longitude from Greenwich.

When the question of adopting one prime meridian for the world was presented to the Conference, it was a grave one, and its importance was duly appreciated. As might have been expected, the first motion made was to adopt the meridian of Greenwich; and equally of course, France objected. Let us see why. If France had consented to change her meridian, all her charts would have had to be eventually issued anew, the plates renewed, and all her school atlases republished. The cost to her would have been millions of dollars. But this is not all; and the point I am about to call your attention to was not — singular to say — alluded to by any delegate to the Congress. At least, I do not find any reference to it in the printed proceedings.

Astronomy teaches us how to regulate time, calculate eclipses, and many other useful things; but I am of the opinion that its greatest usefulness is that it enables us to find our way across the oceans of the world, and bring nations into communication. To read the proceedings of

the Congress one would think navigators were not interested in the prime meridian. The discussion was so highly scientific that the *practical* was scarcely alluded to.

Many navigators know but little of the science of navigation, or theoretical navigation. They understand the practice; and know how to find the position of a ship, and to shape a course. The books on navigation give rules for finding the latitude, longitude, etc.; and these rules are made so plain and practical that any man of ordinary education can follow them. Many captains can find the latitude and longitude, and yet cannot explain the principle.

Now suppose you change the meridian from which he is accustomed to reckon. You confuse him, and he has to learn his rules over again; and while he is doing so, shipwrecks increase in number. If we should change our meridian, and reckon longitude from Washington, marine insurance would probably go up one hundred per cent.

On the proposition to adopt the meridian of Greenwich, twenty-one countries voted in the affirmative, one in the negative, and France and Brazil declined to vote. That is, the countries, generally, using the meridian of Greenwich adhered to it, and those using the meridian of Paris declined to make a change. All of which might have been foreseen before the Congress met.

It is true France proposed and was willing to adopt what she called a "neutral" meridian; but as that would have caused all nations to make a change, it was very wisely rejected.

One argument in favor of the adoption of one prime meridian was that in the case of a ship at sea exchanging longitudes with another, she was sometimes in doubt as to whether the longitude shown was from Greenwich or Paris; but it is usual to *ask*, when in doubt.

French charts are sometimes used by our seamen, though the longitudes are reckoned from Paris. As we know Paris is in longitude 2° 20′ east of Greenwich, we have simply to apply this to our mode of reckoning, in marking a ship's position on the chart. We can use *any* chart. It does not matter what meridian the longitude is reckoned from; all we want to know is the longitude of that meridian east or west of Greenwich.

The proposition before the Conference, to reckon longitude round the world from 0° to 360° was voted down. I was glad to see it; and must repeat that I see no good reason why we should change our time or longitude. We have north and south latitude, east and west longitude, and A. M. and P. M. time.

The only change I see reason for is to change the Astronomical Day to the Civil Day;

and this should be *prospective*. We cannot change it at once without producing confusion. The Nautical almanac is computed for five or six years ahead, using the Astronomical Day. This change might be decided by astronomers, and a certain day and year selected in which to begin the change — say January 1, 1895. After that date, the Astronomical Day would be disregarded and the Civil Day substituted in the calculations for the Nautical Almanac; and the change should be frequently alluded to in the newspapers, so that the attention of navigators would be called to it, and they would be prepared for it.

I see marked on some school atlases the "longitude from Washington." The sooner this is discontinued, the better. As I said in the last *talk*, people, generally, know very little about either time or longitude. The more reason, then, why we should hesitate to make any change in them.

When I was commanding a steamer of the Pacific Mail Steamship Company, in the Pacific, I was frequently asked by my passengers why it was that, in going to China from San Francisco, the navigator "dropped" a day in his reckoning at the 180th meridian, while in going to San Francisco from China he "repeated" a day. This I will try to explain.

The earth turns upon its axis, from west to east, once in 24 hours. It follows, then, that a man travelling round the world in an easterly direction makes one more revolution about the earth's axis than a man who remains at the starting point. He therefore reckons *one day more* in his account. Not that he has lived any longer than the stationary man; he makes it one day more, but as he constantly *meets the sun*, his days are shorter, and are less than 24 hours.

Similarly, a man travelling round the world in a westerly direction makes one revolution *less* about the earth's axis than the man who remains at the starting point. He therefore reckons one day less in his account. In this case he travels *from* the sun, and his days are longer, and more than 24 hours.

Let us suppose two men, A and B, to be at Greenwich. B remains at home, and A travels round the world, at a uniform rate, in an easterly direction. Let us suppose A to go round in 24 of his own days. He must, then, travel 15 degrees in each one of his days; that is, he gains one hour of time each day. When he arrives at Greenwich he will find that by B's account he has been gone but 23 days. The *actual* time of both is, of course, the same. A reckons 24 days, of 23 hours each; B reckons 23 days, of 24 hours each.

Again, let us suppose two men, B and C, to be at Greenwich. B remains at home, and C travels round the world, at a uniform rate, in a westerly direction. Let us suppose C to go round in 24 of his own days. He must travel 15 degrees in each one of his own days; and, as he travels *from* the sun, each one of his days will be 25 hours long. When he arrives at Greenwich, he will find that by B's account he has been gone 25 days. C reckons 24 days of 25 hours; B reckons 25 days of 24 hours, — the same thing.

Now, let us suppose the three men, A, B, and C, to be at Greenwich. A goes round the world in an easterly direction; C goes round in a westerly direction; and B remains at home. It does not matter how fast A and C travel; but suppose they arrive at Greenwich on the same day, and let that day be, by B's account, Sunday. By A's reckoning it is Monday, and by C's reckoning it is Saturday. A has gained a day, and C has lost one. They differ from B one day, and from each other two days. It is on this that Edgar Poe founded his story entitled, "Three Sundays in a Week;" and Jules Verne uses it in his "Around the World in Eighty Days."

The first circumnavigators reckoned in this way; and so it was that Magellan's companions, travelling westward, were one day behind in

their reckoning upon their return home. They stopped at Santiago, Cape de Verde islands, and there the navigators first learned of their being one day behind in their account. It is a curious fact that they put to sea suddenly to avoid being detained by the Portuguese authorities, just as Columbus did from Lisbon upon his return from his first voyage. When Sebastian del Cano — who had succeeded to the command of Magellan's ship — announced that he had sailed around the world, it was at first not believed in Spain; but to the learned the fact that he was one day behind in his reckoning was proof that he had circumnavigated the globe by sailing in a westerly direction.

It was not long after the first circumnavigations that astronomers devised a method by which this confusion of dates might be avoided; and that was to correct the reckoning of time at the 180th meridian.

Ships sailing round the world in an easterly direction, "repeat" a day when they reach the meridian of 180°; and those sailing round in a westerly direction, "drop" a day at the same meridian.

I must call your attention to the fact that if we *drop* a day, that is, omit a day, in our reckoning, we put our time *ahead* 24 hours; and if we *repeat* a day, we put our time *behind* 24 hours. It is necessary you should comprehend

this; and you must observe that we can only correct our time by 24 hours, as otherwise we would turn day into night.

Now, a ship, A, sailing eastward, is, when she arrives at the 180th meridian, 12 hours ahead of Greenwich time; if she keeps on, without correcting her time, she is, upon her arrival at Greenwich, 24 hours ahead, as we have seen. But at the 180th meridian, where she is 12 hours ahead, *she repeats a day*, and this puts her time 12 hours behind Greenwich. By the time she arrives at Greenwich she will have gained the 12 hours she put herself behind, and her day and time will be the same as Greenwich. If, for example, she crosses the 180th meridian on Thursday, she calls the next day Thursday, also; and remember she passes from east to west longitude.

A ship, C, sailing to the westward is, when she arrives at the 180th meridian, twelve hours behind Greenwich time; and if she keeps on without correcting her time, she is, upon her arrival at Greenwich, twenty-four hours behind, as we have seen. But at the 180th meridian, where she is twelve hours behind, *she drops a day*, and this puts her time twelve hours ahead of Greenwich. By the time she arrives at Greenwich she will have lost the twelve hours she put herself ahead, and her day and time will be the same as Greenwich. If, for example, she crosses

the 180th meridian on Wednesday, she calls the next day Friday; and she passes from west to east longitude.

If the two ships, A and C, meet at the 180th meridian, they differ in time twenty-four hours. A calls it Thursday, C reckons it Wednesday. When they correct their times, as just explained, they, in point of fact, *interchange dates*. Thus, A calls the next day Thursday, and C calls it Friday.

This is the way in which navigators correct their date. I have supposed the ships to sail from Greenwich for the sake of illustration. Of course it matters not what port they sail from.

You see now, I hope, why a navigator in going from San Francisco to China drops a day at the 180th meridian. He thus changes his date to the China date. When he returns to San Francisco from China he repeats a day, and thus changes back again to San Francisco time.

TALK THE THIRTEENTH.

Nautical Astronomy. Astronomical Instruments. The Transit Instrument. The Meridian Circle. The Prime Vertical. The Mural Circle. The Equatorial Instrument. The Nautical Almanac. The Early Navigators. The Mariner's Compass. Voyage of Columbus. The Trade-Winds. The Sargasso Sea. Variation of the Compass.

THE plan of this work would not be complete without a few words on what is called nautical astronomy, or astronomy as applied to the science of navigation. When we consider that by its aid the sailor is enabled to find his way across the trackless ocean, we can appreciate one of the practical benefits of the science of astronomy.

I am the more inclined to say a few words on this subject from the fact that most persons are entirely ignorant of it. It has been in my experience to serve on board men-of-war carrying abroad ministers to foreign countries,— men of scholarly attainments, but who had never before left their native shores, — and I well recall their expressions of surprise and wonder when, after a voyage of fifty or sixty days, the destined port

was seen right ahead. I have also when in the merchant marine carried thousands of passengers between the ports of Panama and San Francisco, — I have, indeed, "surveyed mankind from China to Peru," and have had occasion to observe the same ignorance in relation to the science of navigation.

When the "captain" takes his observations for the determination of the latitude and longitude, the majority of the passengers regard it as some mystic operation. Now, although it requires years and experience to make a really good navigator, yet the *principle* by which a ship's position is found at sea is very easy to comprehend, and every one should know it. I purpose in this and the succeeding *talk* to explain it, in as simple language as I can command.

Before entering upon the subject, let us see what astronomers are doing in their observatories, and glance at some of the instruments they are using.

A telescope is an astronomical instrument; or perhaps we had better say, it is the "sight" attached to fundamentally different instruments. The Transit Instrument is a telescope mounted so that, as it turns upon its axis, it describes the plane of the meridian. The axis points east and west. When the telescope is horizontal it points due north or south. It can be revolved

upon its axis from north to south, and its use is to determine the right ascensions of the heavenly bodies, and their transits. By "transit" is meant the passage of a body across the meridian, or its *culmination*, as it is also called.

The telescope of the transit instrument cannot be pointed either to the right or left, and its use is limited to the observation of heavenly bodies when on the meridian. This is only a very short interval of time; the object enters the field of the glass on one side, and in a few seconds disappears on the opposite side.

If we attach a graduated circle to the axis, at right angles to it, we can measure the declination of a celestial body, or we can measure its meridian altitude. It is then called a Meridian Circle. This instrument is sometimes mounted so that its axis points north and south. The telescope then points due east and west; and the instrument is called a Prime Vertical, for the reason that the telescope, when revolved upon its axis, moves in the plane of that circle of the celestial sphere called the prime vertical.

The Mural Circle is the same as a Meridian Circle in its use. The mounting is different. The horizontal axis is supported at one extremity only, and this extremity is let into a stone wall; hence, mural, from *murus*, a wall. It is not so accurate an instrument as the Meridian Circle, as we cannot reverse it in deter-

mining its error, and its use has been nearly abandoned.

The Equatorial Instrument is mounted so that its main axis points to the poles of the heavens. It carries two circles, one of which is called the hour circle, and the other the declination circle. By means of a clock-work arrangement the telescope is made to revolve upon its polar axis once in a sidereal day. We see, then, that having once set it upon a star, *it follows that star from its rising to its setting*, and has it in view always at the same point in the focus of the object glass. The telescope revolves in a direction contrary to the motion of the earth on its axis.

This is the instrument used by the astronomer who wishes to observe a celestial body for a long time, to study its physical constitution, etc.

Astronomers use also Zenith Sectors, Alt-azimuths, and some other instruments which it is not necessary to describe.

Now, while some observers are engaged in studying the physical constitution of the heavenly bodies, fixing the positions of the stars, calculating eclipses, etc., others are at work on the necessary calculations to be inserted in a book called the "Nautical Almanac," or the *Ephemeris*, a book especially designed for the use of navigators. In this book we find the

right ascension and declination of the sun, moon, planets, and principal stars. We find, also, the apparent semi-diameters of the sun and moon, the Equation of Time, and, indeed, all that is useful to the navigator in determining his position at sea.

Not only that, but these elements are calculated for years ahead; so that when a ship sails on a three years' cruise, the navigator is provided with nautical almanacs for four or five years in advance.

Let us now glance at the early navigators. Our books say the Phœnicians were the earliest navigators; but we know almost nothing concerning the early voyages of the Chinese, and other Eastern nations. One thing is certain: they kept near the shore. In the voyages of Saint Paul we read that, on his last voyage from Cesarea to Rome, his ship *coasted* along the shores of Asia Minor, until it was driven off by the fury of a tempest, and finally wrecked on the island of Melita, or Malta, as is supposed.

Why did the early seamen keep near the shore? Because they had no compass.

Most of the ancients knew that loadstone attracted iron; and it must have been soon discovered that a piece of iron rubbed on a loadstone becomes a magnet, and will attract other

pieces of iron, and will, moreover, point to the north when freely suspended.[1]

Some writers assert that this was Gioja's discovery; but it is said the Chinese had, in Marco Polo's time [A. D. 1265], on the northern confines of their country, magnetic needles suspended to point out the way to travellers coming from the north. I have sometimes thought it was in this way the Chinese happened to mark the south point of their compass cards, as we do the north point.

I have read an account written by a French gentleman who, somewhere about the eleventh century, made a voyage in an Arabian ship from one port in the Mediterranean to another. He relates that, the sky being overcast, the captain placed a piece of iron on a cork, floated it in a basin of water, and carefully observed the direction in which it pointed.

Other writers assert that Roger Bacon, in the thirteenth century, discovered the polarity of the needle. But at all events, we see the mere fact that a needle, floating in a basin of water, would point to the north, was of very little practical use to the first navigators. When the weather was clear they steered by the sun by day, and the stars by night.

[1] Dr. Johnson says: "The lode-star is the *leading*, or guiding, star; that is, the pole-star. The magnet is for the same reason called the *lode-stone*, — either because it leads iron, or because it leads the sailor."

The weight of testimony goes to show that the mariner's compass was discovered, or invented, by Flavio Gioja, in the early part of the 14th century. He was a native of Amalfi, a small town near Naples; and the mariner's compass being of all the instruments used by navigators the most useful,[1] I will proceed to describe it.

It consists of a Needle, a Card, and a Bowl. The card is circular, and is divided into 32 equal parts, called *points*, and these points are also divided into halves and quarters. Since the circumference of a circle contains 360°, each point equals 11° 15′. The Cardinal Points are north, south, east, and west. "Boxing the compass" is to repeat all the points of the card; thus, commencing at north, we say, N.; N. by E.; N. N. E.; N. E. by N.; N. E.; N. E. by E.; E. N. E.; E. by N.; E.; and so on round to north again. Beginners are made to "box the compass," to teach them the points and their names.

The needle is attached to the under part of the card, with its north end directly under the north point of the card. In its centre is a socket, and it is placed on a pivot which projects from the bowl. The bowl is made of brass, or wood.

[1] Columbus crossed the ocean with barely any other instrument than a compass to guide him; it would puzzle a navigator of the present day to do so without one.

Now as the needle moves on the pivot it carries the card with it, and the north end points north. The bowl containing the card is placed in a stand, called the Binnacle, which is placed just in front of the helmsman. The bowl has a black vertical line drawn in it, and is placed so that this "mark" is in the vertical plane passing through the keel of the ship. It is called the "lubber's mark," and it indicates the direction of the ship's head. The bowl is suspended by *gimbals*, so that however much the ship may roll and pitch, the card is always horizontal.

You see, then, the point of the compass card which is *on* the "lubber's mark" shows the direction of the ship's head; and the helmsman, after receiving the "course" to be steered, moves the helm until that point of the card is on the "lubber's mark." He keeps that mark on, until he receives orders to change the course.

When Flavio Gioja made his first compass — as the kingdom of Naples at that time belonged to the Royal family of France — he marked the north point of the card with a *fleur-de-lis* — and the mark has been preserved.

In the 15th century[1] the great maritime nations were Portugal and Spain — or at all events,

[1] The Encyclopædia Britannica says: "John II., who ascended the throne of Portugal in 1481, employed Roderick

they were the nations that were engaged in making new discoveries. The Portuguese confined themselves to endeavoring to reach the southern extremity of Africa. In 1487 Bartholomew Diaz succeeded in reaching it; and in 1497 Vasco de Gama doubled it, and arrived at Goa, on the west coast of Hindostan. It is worthy of note that Bartholomew Columbus, a brother of Christopher Columbus, accompanied Diaz on his voyage to the Cape.

Leaving the Portuguese navigators, let us turn our attention to Christopher Columbus, the boldest navigator of his day; indeed, according to my view, the boldest man of whom we have any account in history. While all the other seamen of the known world were creeping along the shore, he heroically sailed forth on the broad ocean.

I will call to your attention three points. First, what astronomical knowledge did he possess? Secondly, what reasons had he for asserting he could reach China by sailing westward? Thirdly, what nautical instruments did

and Joseph, his physicians, and Martin de Bohemia from Fayal, to act as a committee on navigation. They calculated tables of the sun's declination, and invented the astrolabe, — or at least recommended it as more convenient than the cross-staff. The navigator of that day had a compass, a cross-staff or astrolabe, a moderately good table of the sun's declination, a correction for the altitude of the pole star, and occasionally a very incorrect chart."

he have to assist him in finding his position and shaping his course?

(1). As Copernicus only published his work in 1543, Columbus, who sailed in 1492, did not know anything about the Copernican theory. He probably believed in the Ptolemean theory, and supposed the sun and other heavenly bodies to revolve about the earth. But he believed the earth to be round, and that he could reach the eastern confines of Asia by sailing westward. He did not *know* it, as we do, because no ship had ever sailed round it. He greatly underestimated the dimensions of the earth; he supposed it much smaller than it really is. We have seen that its exact measurement was not completed until the middle of the 18th century.

He had no means by which to ascertain his longitude; but he had an instrument, called the *astrolabe*, by which he could measure the altitude of the sun and stars. If he was provided with an *ephemeris*, giving the sun's daily declination, he was able to find his latitude by that luminary. I think it more probable he found his latitude by observations of the pole-star. The altitude of the pole is the latitude of a place, and if there were a star exactly at the north pole of the heavens, its altitude would be the same as our latitude. Now the pole-star is not exactly at the north pole of the heavens, it is 1° 18′ removed from it. But it is easy to see

that when it is at its upper culmination, the latitude will be equal to its altitude *minus* 1° 18′; at its lower culmination, the latitude is equal to its altitude *plus* 1° 18′ — and when the star is due east or west of the pole, its altitude will be equal to the latitude, since in this case it is just as high as the pole.

I am the more inclined to think Columbus discovered his latitude by the pole-star from the fact that the oldest works on navigation I have read give the positions of the "dipper" when the pole-star is in any of the four positions I have just mentioned. Thus, one position of the "dipper" indicated that the pole-star was at its upper culmination; another, that it was due east of the pole, and so on. The navigator knew from these positions what correction to apply to the observed altitude of the star. Of course this was before the publication of an *ephemeris.*

(2). What reasons had he for expecting to find land to the westward?

We know that Columbus had made a voyage to Iceland before 1492. Iceland was discovered by the Norwegians in 860, and in 960 a Norwegian colony was established on the east coast of Greenland. In 1001 America was discovered by an Icelandic voyager, somewhere about the latitude 41° or 42°; and it was known and visited by the Northmen for some centuries after. The

Northmen are supposed to have landed in the vicinity of Cape Cod. Why they should have described the climate as mild, and why they called the country Vinland, has always been a puzzle to me. The climate is not mild; nor is there, in New England, a superabundance of grapes.

Columbus may have learned at Iceland of the colony in Greenland, and the voyage of the Northmen. His profession of a seaman would naturally put him in the way of picking up information of the kind; and moreover, he was a "maker of maps."

But Columbus, whatever he may have learned in Iceland, certainly sailed on his voyage with a definite object; and that was to find land in about latitude 28° north. If he had simply intended to visit the land discovered by the Northmen, he would have sailed about *west by north* from Palos. What did he do? He went first to the Canary Islands, in latitude 28° N., and from thence sailed *due west.* Had he not been diverted from his course by the opinions of the Pinzons, and the flight of birds to the southward which caused him to sail more in that direction, he would have struck the coast of Florida in the neighborhood of Cape Carnaveral.

I confess I have never been able to discover why Columbus adhered so obstinately to his "due west" course *from the island of Gomera.*

Is it possible that he had some information unknown to the rest of the world?[1]

(3). What nautical instruments did he have? The compass, and a rude instrument called an astrolabe, to observe altitudes. He could determine his latitude, but his longitude he could only guess at. He measured time by an hour-glass. This glass was turned at the end of every hour; and it was in use for many years after Columbus's time. This is why we see in the

[1] This point has been much discussed. M. Marmontel in "The Incas, or the Destruction of the Empire of Peru," Dublin, 1777, says: —

"In 1484 Alonzo Sanches de Huelua, going from the Canaries to Madeira, had been driven, it is said, almost to San Domingo. He returned to Tercera with only four of his companions. In this island Christopher Columbus, a famous pilot, by birth a Genoese, received them. They all died in his house, and it is reported that from their journal he undertook the discovery of America."

And Fructuoso says that a Biscayan vessel arrived at Funchal, Madeira, in 1486, and that the pilot gave Columbus, who sheltered him, the same information.

All this appears sufficiently circumstantial, though neither Marmontel nor Fructuoso give their authority.

Per contra: We know that Columbus went to Spain in 1484, and that he had previously offered his services to Genoa and Portugal. Furthermore, we find him as early as 1474 expounding his views to Paolo Toscanelli, the famous cosmographer.

Nevertheless, all this does not explain why he sailed due west *from Gomera;* for although, as early as 1474, he believed he could reach the Indies by sailing to the westward, he *may* have received information between that date and 1492 which induced him to pursue the course he did. *Quien sabe?*

old voyagers such expressions as, "we fought this tall ship for three glasses," meaning three hours. It was their only means of measuring intervals. Frequent references are made by the old poets to the use of the hour-glass. Thus, Shakspeare says, —

> "Or four and twenty times the pilot's glass,
> Hath told the thievish minutes how they pass."

Columbus had no means for determining the speed of his ship, so far as I know. The first mention of the log and log-line is in Pigafetta's account of Magellan's voyage in 1519.[1] He must have estimated the number of miles run daily.

Let us now glance at this voyage of Columbus, see what scientific discoveries he made, and what land of the western hemisphere he first saw.

Sailing from Palos in Spain he touched at the Canary Islands, and then steered west across the Atlantic Ocean. He found, to his surprise, the wind blowing constantly from the northeast. This was a fair wind; but the sailors, already sufficiently in dread of the voyage, complained

[1] This is from my recollection of Pigafetta's narrative. The Encyclopædia Britannica says, however: "There was not till 1607 any means whatever of measuring a ship's progress through the water, and none in general use till 20 or 30 years later."

that they would never be able to get back to their native land. This wind, that blows almost constantly from the northeast in the north tropic zone, is known as the trade-wind; so called, because these winds facilitate trade.

This will be a good time for me to explain the cause of these winds, as I promised in a former *talk* I would do.

All winds are caused by the sun's heat, and the earth's rotation upon its axis. The trade winds blow between the parallels of about 25 degrees north and south of the equator. They blow from the northeast in north latitude, and from the southeast in south latitude, and are caused by the air being heated in the equatorial regions. The hot air rises, thus creating a vacuum which the colder air from the north and south rushes in to occupy. If the earth did not revolve upon its axis these winds would be from the north and south; but in consequence of its movement from west to east, and the fact that the diurnal velocity is greater at the equator than in the frigid and temperate zones, these winds appear to *hang back*, as it were, and thus blow from the northeast and southeast.

This apparent change in the wind's direction, in consequence of these two motions, is somewhat like the cause of the aberration of light.

The theory in regard to the movement of the heated air that rises at the equator is that it

returns in the direction of the poles; and becoming cold, it falls again to the earth, somewhere about latitude 30°, and as its velocity to the east is now greater than the parallel of 30°, it becomes a southwest wind in the northern hemisphere, and a northwest wind in the southern one.

A knowledge of the winds is essential to the seaman, especially in vessels propelled by sails alone. Speaking generally, we find, in the northern hemisphere, westerly winds between the parallels of 50° and 30°; then a belt of calms (called the "horse latitudes"[1]) for a few degrees; then from about the parallel 25° to near the equator, northeast and easterly winds; and then a belt of calms again for a few degrees on both sides of the equator. Proceeding south, we strike the southeast trades until we get to about 25°, then a belt of calms, and after that northwest and westerly winds. The trade-winds are modified by the change in the sun's declination, and near the land are changed into land and sea breezes. We have local winds, such as the sirocco, the harmattan, the monsoons, etc., all of which are treated of in our books on meteorology.

[1] This belt of calms received the name of "horse latitudes" from the New England traders, who formerly carried large numbers of horses to the West India islands, many of which were lost in these calms.

The first discovery made, then, by Columbus, was the trade winds.

Proceeding on his voyage, he soon found a portion of the ocean which was covered with sea-weed; and so thick was it that his vessels, being small, were impeded by it. This weed bears globules, and Columbus's sailors thought they resembled a grape grown in Portugal, called the *sargasso*. This name was given to that portion of the ocean by Columbus. It is known as the Sargasso Sea, and the weed is found there now just as it was in 1492.

The next discovery made by our voyagers was a more startling one, and that was that the north point of the needle did not point to the same star that it did in Spain. We are told the sailors were very much alarmed by this; and well they might be, for if the *compass* failed them, all hope of finding their way back again was gone.

This is known as the "variation of the compass." The needle does not point in the same direction at different places on the earth's surface. At some places it points due north; at others it points to the east of north; and at others again to the west of north. Moreover, it is constantly changing, though very, very slowly. We do not know the *cause* of this variation, any more than Columbus did; but we can find its amount by observations of the heavenly

bodies, and apply it to obtain the true north point.

Columbus, then, had made three discoveries before he discovered land: The trade-winds, the Sargasso Sea, and the variation of the compass.

What land did he first see? When Washington Irving was writing the History of Columbus he engaged Captain Alexander Slidell Mackenzie, of the United States Navy, to investigate this point. After an exhaustive analysis, the captain came to the conclusion that the first land sighted by Columbus was the island in the Bahama group, called now Cat island. It was called by the natives Guanahani, and by the Spaniards San Salvador.

The point has been disputed. The English say it was Watling's island; the Spanish historian Navarrete thinks it was Turk's island; and books have been written to prove that it was Mariguana island, and Samana island or Atkins Key.

The question must remain forever undecided. We know that Columbus, after leaving the first island, sailed along the coast of Cuba, and then along the coast of Hayti. On the north side of the latter island he built a fort, called La Navidad, left a garrison there, and returned to Spain. All we know about this place is that it was

probably near the present town of Cape Haytien.

Upon the return voyage Columbus was forced by the easterly winds and Gulf Stream to sail to the northward until he got to the zone of the westerly winds; so in addition to his other discoveries he may be said to have discovered the best route from Spain to the West Indies, and return.

I have dwelt upon Columbus's voyage, his small astronomical knowledge, and his imperfect nautical instruments, because in my next *talk* I intend to tell you how a navigator of the present day is supplied; what correct charts, instruments, etc., he is furnished with, and how he finds his position at sea.

When I look back upon my own voyages and recall the many anxious moments I have passed when looking for a port at night, and when I compare my own situation, supplied with accurate charts, perfect instruments, good sailing directions, everything in short that science can supply, and then think of Columbus in his little bark, his only instruments an imperfect compass and a rude astrolabe, *sailing forth upon an unknown sea*, I must award to him the credit of being the boldest seaman that ever "sailed the salt ocean."

TALK THE FOURTEENTH.

The Sextant. Index Correction. Semi-Diameter. Dip of the Horizon. Refraction. Parallax. Departure. Course and Distance. Log-Book. Log and Line. Difference of Latitude and Difference of Longitude. Method of finding the Latitude by the Sun's Meridian Altitude. The Chronometer. Method of finding the Longitude by Chronometer. The Lunar Observation. Charts. Azimuth and Amplitude. Calculation of the Time of Sunrise and Sunset. The Artificial Horizon. Error and Rate of a Chronometer. Distance at which an Object is Visible at Sea. High Water. The Merchant Marine.

LET us see what a navigator of the present day provides himself with before starting on a cruise. The astronomical instruments I have mentioned as being in use in all observatories, — the meridian circle, the equatorial, etc., — cannot be used on board ship. Why? The earth, as we have seen, is a movable observatory, — that is bad enough, — but a ship is a rolling and pitching observatory. Any of the instruments I have named would be thrown out of adjustment at the first swell of the ocean.

Fortunately the seaman has been supplied with an instrument which overcomes this diffi-

culty. It is called the *sextant.* It is held in the hand, and by a turn of the wrist the observer can keep the plane of the instrument in the plane of the two bodies whose angular distance he wishes to measure. It can be used to measure vertical angles, horizontal angles, or any other angles. In lunar observations the observer measures the angular distance between the moon and either the sun, a planet, or a lunar star;[1] but the most common use of the sextant is to measure the altitudes of the heavenly bodies. By altitude is meant the *angular* height of a celestial body above the horizon.

The navigator, then, supplies himself with a compass, sextant, an artificial horizon,[1] chronometer, log and log-line, hour-glasses, charts, box of instruments, barometer, thermometer, work on navigation, sailing directions, nautical almanac, and many other things not necessary to mention. It is my design to take you on a cruise with him, — say from New York to Rio de Janeiro, — and explain to you how he finds his daily position, and finally reaches his port.

When the altitude of the sun is observed it has to be corrected for the index error of the sextant, for semi-diameter, dip, refraction, and parallax. I will take up these corrections *seriatim.* The "index error" is the error of the sextant. All instruments have "errors." No

[1] See pages 237 and 243.

instrument ever was, or can be, made perfect, and all observations whether made on shore or at sea have to be corrected for instrumental errors.

The "index correction"[1] of the sextant is readily discovered by measuring the angular diameter of the sun; it is *plus* or *minus*, as the case may be.

Let us see what the correction for semi-diameter is. When we measure the altitude of the sun, what we want is the *altitude of its centre.* Now there is no mark at the centre by which we can observe with the sextant when it is on the horizon; so we bring the sun down to the horizon so that its lower limb (as we call it) is in contact with it, and then add the semi-diameter. This gives us the observed altitude of the sun's centre.

Thus, in the diagram (Fig. 11) suppose A B to represent the line of the horizon; S represents the sun as it appears when "brought down" with the sextant; and S′ shows its position after the semi-diameter has been added.

[1] If a sextant is in perfect adjustment the true and reflected images of the sun, or other body, exactly coincide when the zero point of the index is on the zero mark of the graduated arc. But the horizon and index glasses may not be perpendicular to the plane of the instrument, or they may not be parallel when the index is on 0; or there may be some defect in the glasses. These errors make up what is called the "Index Correction."

The next correction is for "dip of the horizon." I have not had occasion to mention it before in the course of these *talks*, except that

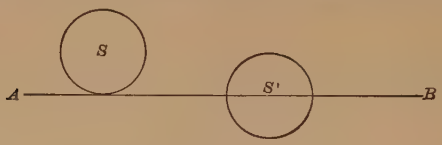

FIG. 11.

I once said, "The higher you ascend the farther you can see." This is because the earth is round.

In the diagram (Fig. 12) let O be the centre of the earth; A an observer, elevated above its surface by the distance A B. The horizontal line A E represents the rational or true horizon, and the line A D, tangent to the earth's surface at C, the visible or sensible horizon. Now when we measure the altitude of S, the sun, we measure the angle S A D; but the altitude we require is the angle S A E; hence we measure *too much*, by the angle E A D. Our horizon has "dipped" below the rational horizon by the angle E A D, and this angle is called the dip. We see, then, that the dip must be subtracted from the observed altitude; and that its amount depends entirely upon the height of the observer. Tables are inserted in our books on navigation giving the dip corresponding to heights up to one hundred feet. The angle

E A D is small even up to one hundred feet, being for that height but 9′ 51″. Navigators on the decks of their vessels are rarely over twenty-five feet above the level of the sea.

I must call to your attention that the height A B, in the diagram, is very much exaggerated. All diagrams of the kind are. They are only

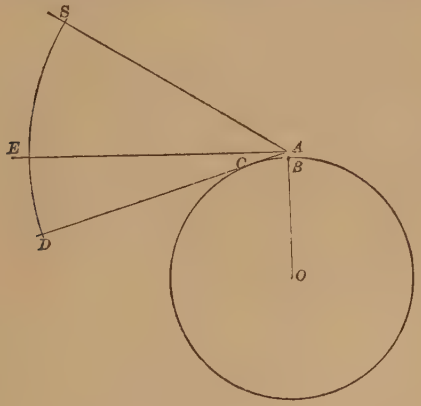

FIG. 12.

designed to illustrate. If I should attempt to draw it on a scale, the angle E A D, representing the dip, even for one hundred feet, would be less than a pencil-mark. The distance O B being the radius of the earth, or four thousand miles, and the distance A B only fifty or one hundred feet.

The correction for refraction is the most vexing of all the corrections, because it depends

for its value upon the earth's atmosphere, which is constantly changing in density. When a ray of light passes obliquely from one medium to another of different density it is bent, or refracted, out of its course. This is best seen by placing a stick obliquely in water. Now the earth's atmosphere is not of uniform density; hence a ray of light from the sun, or other celestial body, upon entering it is bent more and more downwards, describing a curve, until it enters the eye of the observer. The observer sees the body in the direction of a line drawn tangent to the curve at the moment it enters the eye. He therefore sees it too high. In the diagram (Fig. 13) let O be the centre of the earth, and A an observer on its surface. Let B C represent the upper limit of the atmosphere. Let S be any celestial body, and S D a ray of light from it which enters the earth's atmosphere at D; it will then be refracted downwards, in a curve, until it reaches the eye of the observer at A; and he will see it in the direction of the line A S′, tangent to the curve at A, where it enters the eye of the observer. That is, he sees it too high; hence the correction for refraction must be subtracted from an observed altitude. Refraction, you observe, depends upon the altitude of a heavenly body; it is greatest when the object is in the horizon, and nothing when it is in the zenith. Tables of

refraction are calculated for all altitudes, from 0° to 90°, and inserted in works on navigation. It is a small quantity. The refraction for 0°,

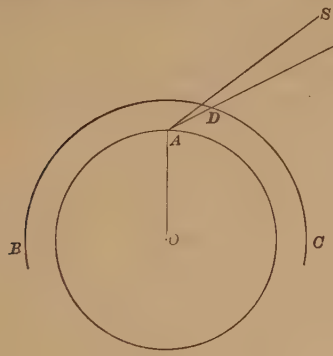

FIG. 13.

that is, when the body is on the horizon, is 33′; and for 90° it is zero.

As the apparent,[1] or angular diameter of the sun is about 33′, the effect of refraction is to

[1] The apparent *enlargement of the sun and moon in the horizon* arises from an optical illusion. These bodies, in fact, are not seen under so great an angle when in the horizon as when on the meridian, for they are nearer to us in the latter case than in the former. The distance of the sun is, indeed, so great that it makes very little difference in his apparent diameter whether he is viewed in the horizon or on the meridian; but with the moon the case is otherwise; its angular diameter when measured with instruments is perceptibly larger at the time of its culmination. (Olmsted.)

"Yet, like the sun, seems larger at his setting."
(Robert Blair, 1700.)

elevate it by just its diameter when it is rising or setting; so that when we see the sun with its lower limb just touching the horizon, it is really just below it. Another effect is to make the day a little longer.

The refraction is the same for all celestial bodies; it depends solely upon the altitude of the body.

The last correction I have to explain is parallax. I have already told you what is meant by the horizontal parallax, and parallax in general.

Observations of the celestial bodies comparatively near the earth, when made at different places, do not give the same result, because they are viewed from different points. To correct this, astronomers have agreed to reduce them to what they would be if they had been made at the centre of the earth; and this correction is called the parallax. It is the different direction in which a celestial body appears, as seen by an observer on the earth's surface and by one at its centre.

In the diagram (Fig. 14) let O be the centre of the earth; A an observer on its surface; and S, S′, two positions of a heavenly body. When the object is at S, that is, on the horizon, an observer at O would see it in the direction O S; an observer at A, in the direction A S. The angle A S O is the horizontal parallax. It is

the angle subtended at S by the earth's radius.

When the object is at S′, an observer at O would see it in the direction O S′, and an ob-

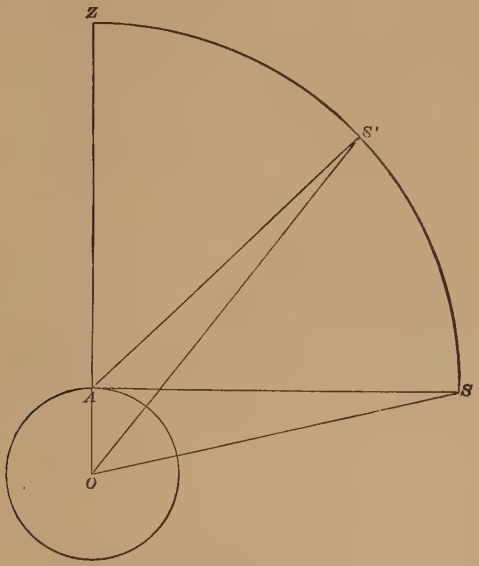

FIG. 14.

server at A would see it in the direction A S′. The angle A S′ O is the parallax in altitude.

The correction for parallax is additive to an observed altitude; for it is evident that we see the object too low. The parallax is greatest when the object is in the horizon; and it is nothing when the object is in the zenith. This is clearly

seen by a reference to the diagram. The parallax, you observe, depends upon the distance of the body. It has nothing to do with its magnitude. The moon has the greatest parallax, then the nearest planets, and then the sun. The stars (with the exceptions I have mentioned) have no parallax of this kind. Tables of Parallax are inserted in our books on navigation, calculated for all altitudes, from 0° to 90°; and, as you see, there must be separate tables for the sun, moon, and planets.

Let us suppose our navigator to sail from New York, bound to Rio de Janeiro. Just before he loses sight of the land he takes his "departure," as it is called; that is, he observes the bearing of, say, Sandy Hook, and estimates its distance. The reverse bearing[1] is the first course entered on the log-book, and the distance is marked opposite to it. Every hour after this the log is thrown, and the course and distance run entered on the log-book. The theory of finding the speed of the ship by means of the log-line is this: Suppose we should throw overboard a log with a line attached to it, and then (supposing the log to remain stationary) we should let the line run out for the space of one

[1] By "reverse" bearing is meant the opposite bearing. Thus, if Sandy Hook bears west-northwest, distant 10 miles, the first course and distance is east-southeast 10 miles, starting from Sandy Hook.

hour, and then haul it in and measure it. Would not that tell us how many feet, or yards, or miles, the ship had sailed in an hour? Well, this is exactly the principle by which we determine a ship's rate of sailing. We make it *practical*, which this method certainly is not. A sea-mile is about 6,120 feet; and 51 feet is $\frac{1}{120}$ of a mile, and 30 seconds is $\frac{1}{120}$ of an hour. So if we put marks on the line at distances of 51 feet apart and notice how many of these marks run out in 30 seconds, it tells us how many miles per hour the ship is sailing at the time the log is thrown; and if we suppose the rate has been uniform for an hour, it shows how many miles the ship has made in that time,—for 30 seconds is the same part of an hour that 51 feet is of a mile.

The man, then, who heaves the log, knows the rate of sailing by the number of the knots in the mark he holds in his hand at the expiration of the 30 seconds; and, no doubt, in this way a sea-mile came to be called a knot.

Sand-glasses are used by seamen in heaving the log, as they are less liable to be broken than watches, and are more easily observed at night. I believe this is about the only use now made of sand-glasses, though formerly seamen used hour-glasses entirely for their time. For convenience in separating the knots into eight fathoms of six feet each, navigators use

28-second glasses instead of 30-second glasses, but the principle is the same.

The log-chip is a triangular piece of wood, one side of which is weighted with lead. It is attached to the end of the log-line by a cord from each of its three corners, forming what we call a bridle. When it is thrown into the water the lead causes it to assume an upright position; and it offers sufficient resistance to cause the log-line to run off the reel, and itself remains stationary. This is not absolutely true, but it is sufficient for our purpose.

Well, then, the course and distance being entered on the log-book every hour, the next day, at noon, the navigator takes all the courses and distances, and by means of a "traverse table," inserted in his book on navigation, he finds his difference of latitude and difference of longitude made good, and applies it to the latitude and longitude of Sandy Hook. He thus finds his own latitude and longitude. This is what is called the "dead reckoning." It is independent of celestial observations; it depends upon the compass and log-line only. This reckoning is kept from day to day because it is what we depend upon when we can get no celestial observations, on account of fog, or cloudy weather.

But the *true* position of the ship is found by observations of the sun, moon, planets, and

stars. The principle being the same for all, I will only speak of observations of the sun, — that being the body which we observe ninety-nine times in a hundred. I will first explain the theory of finding the latitude. It is very simple; as is also that by which we find the longitude.

The latitude of a place is its distance north or south of the equator. To find our latitude, then, we have to find the distance of our zenith from the equator.

Now the navigator goes on deck with his sextant and observes the sun's meridian altitude. He does this by commencing his observations about ten minutes before noon, and noting the greatest altitude the sun attains. The sun is then on the meridian, and it is twelve o'clock apparent time. After the sun has crossed the meridian, it begins to fall; this is called "dipping."

The sun's meridian altitude subtracted from 90°, gives us the distance of the sun from the zenith — or its zenith distance. The Nautical Almanac contains the sun's declination, or its distance from the equator, north or south. Now then, as we know the distance of the sun from our zenith and the distance of the sun from the equator, we have only to combine the two to find the distance of our zenith from the equator, or our latitude. For example, suppose the sun's meridian altitude to be 60°, bear-

ing south. Its zenith distance then is 30°. Suppose the sun's declination to be 10° north. We have then for the distance of the zenith from the equator, or the latitude, 30° + 10° = 40° N.

If the observer happens to be in the Arctic regions during the summer months, the sun will always be above the horizon, and sometimes will be on the meridian twice[1] in the course of twenty-four hours, — once bearing south, and once bearing north. The latter is called its lower culmination. If we take its altitude at that moment, the latitude is found by adding it to the sun's polar distance (that is, 90° *minus* the sun's declination.) This gives us the distance of the pole above the horizon, and this is equal to the latitude.

At the equator the pole is on the horizon; and for every degree we move north, the pole rises one degree above the horizon. Hence we have for another definition: the latitude of a place is equal to the altitude of the elevated pole.

The theory by which we find the latitude, then, you observe, is very simple. We generally use the sun, but we use also the moon, planets, and stars. The "observed altitude," you must understand, is corrected for index-error, semi-diameter, dip, refraction, and parallax. The altitude of a star, however, requires no correction for semi-diameter and parallax, as it has none.

[1] It depends, of course, upon its declination.

What I have said concerning the method of finding the latitude by the meridian altitude of a celestial body appears very clear from an inspection of the following diagram.

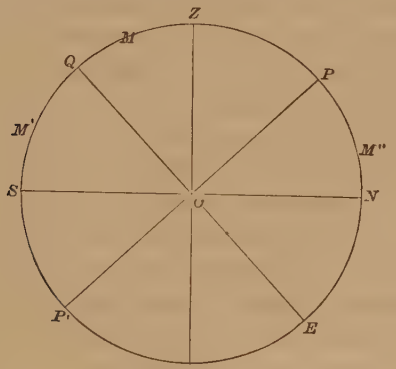

FIG. 15.

Let the diagram be a projection of the celestial sphere on the plane of the meridian N. Z. S. Z is the zenith; N S the horizon; P the elevated pole; P P′ the axis of the sphere; E Q the equator; Z Q the distance of the zenith from the equator, and P N the altitude of the pole. Z Q and P N are each equal to the latitude L. Let M, M′, M″, be three positions of the sun on the meridian; Q M, Q M′, and E M″ represent its declination, d; and Z M, Z M′, and Z M″, represent its zenith distance, z.

When the sun is at M, north of the equator, $L = z + d$; when the sun is at M′, south of the

equator, $L = z - d$; and when it is at M″, below the pole, L = altitude $+ p$, the polar distance, as I have said.

I will now tell you how we find the longitude by chronometer.[1] A chronometer is a large watch of peculiar construction, made especially for the use of navigators. It is suspended by gimbals, as a compass-bowl is; and the object is to keep the face of the chronometer horizontal. It is kept in a box in the navigator's cabin, and preserved as much as possible from changes of temperature and jars; for upon it depends our means of finding the longitude.

The chronometer shows the *mean Greenwich time*. It is set at the observatory to that time, and then sent to the navigator. Now it does not really show the exact hour, minute, and second of Greenwich time. As I have said, a *perfect* instrument was never yet made, and never will be. But before leaving port the navigator knows the *error* and *rate* of his chronometer; that is, how much it is *fast* or *slow* of Greenwich mean time, and what it *gains* or *loses* daily. Knowing the *error* he applies it to the chronometer time, adding or subtracting as the

[1] The Encyclopædia Britannica says: "Watches were unknown till 1530, and immediately Gemma Frizou, or Frisius, seized the idea for the purpose of ascertaining the difference of longitude between two places."

case may be, and finds the *true Greenwich time*. We see, then, the navigator has only to look at his chronometer to discover the mean Greenwich time.

Now by observations of the heavenly bodies we can find our *mean local time*. Here, then, we have at once the theory of finding the longitude by chronometer. The difference between our time and the time at Greenwich is our difference of longitude. There are fifteen degrees of longitude to one hour of time. We calculate our mean local time, the chronometer gives us the mean Greenwich time, the difference between the two is our difference of longitude *in time;* we multiply it by fifteen, and we find our longitude in degrees and minutes of space.

Let us see how we compute our local time. I see in "Lockyer's Astronomy," page 100, American edition, the following: —

"By this easy process navigators determine their longitude at sea. Taking with them a chronometer (an accurate watch) set according to the time of a given place (as Greenwich or Washington), they ascertain the local time by observing with the sextant when the sun is at its highest point; it is then noon. Reducing the difference of time to difference of longitude they find that they are so many degrees east or west of the meridian of the place for which their chronometer is set."

All this is sufficiently absurd; but I do not hold Mr. Lockyer responsible for the statement, as I have seen it in some American astronomies. It agrees with what I have had occasion to observe concerning the so-called "navigation" taught in our colleges and schools.

If we *could* note the exact moment the sun is on the meridian it would then be twelve o'clock, *apparent* local time; and by applying the equation of time to it we should have the *mean* local time; and the difference between *it* and the time shown by the chronometer at the moment of observation would be the difference of longitude in time. But we cannot determine the *instant* of the sun's attaining its meridian altitude. It is true that in the tropics, where the sun has always a high meridian altitude, we can mark it pretty closely; but in other latitudes, especially when the sun's meridian altitude is low, we cannot mark it within three or four minutes, — and a minute of time represents fifteen miles of longitude! *Navigators never rely upon this method to determine the longitude.*

The longitude by chronometer is found thus: In the morning or evening when the sun is fifteen or twenty degrees high, and is rising or falling rapidly, the navigator observes its altitude. He calls it a "time" sight; because he

is really going to compute his local time by means of the altitude he has just measured. At the instant of observing the altitude, he notes the time by his chronometer.

He then solves a spherical triangle, of which he has given, the three sides, namely: the altitude just observed, the latitude, and the sun's polar distance. The latitude is really found at noon, as I have just explained, and is "worked back" to the time of taking the morning observation. The polar distance of the sun is ninety degrees *minus* its declination, which declination is found in the Nautical Almanac.

He solves the triangle, then, by means of its three sides and finds the angle at the pole. This angle is the sun's hour angle, or the apparent local time. To the apparent time he applies the equation of time (found also in the Nautical Almanac), and this gives him his mean local time. The difference between the mean local time and the Greenwich time (as indicated by the chronometer), is the difference of longitude in time.

This is the simple theory of finding the longitude by chronometer. It is very easily comprehended. Let the diagram (Fig. 16) represent the projection of the celestial sphere on the plane of the horizon of a place, Z is the zenith, N Z S the meridian, P the elevated pole, M the position of the sun, or any other celestial

body. The navigator solves the triangle Z P M of which he knows P Z, the complement of the latitude; P M, the polar distance; and Z M, the zenith distance of the object, and he finds the angle Z P M, or the hour angle.

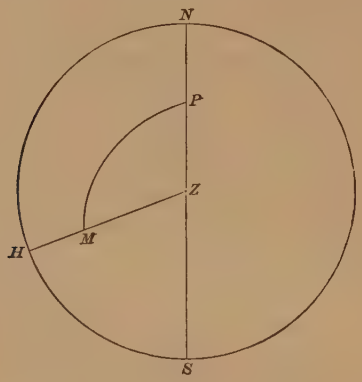

Fig. 16.

The longitude by chronometer can be found by measuring the altitude of the sun, moon, planets, or stars; the principle is the same for all.

Before the introduction of chronometers the longitude was found by what is called the "lunar observation," first proposed by John Werner of Nuremburg, and improved upon by Maskeline.[1]

[1] The Encyclopædia Britannica says: —

"Johann Tobias Mayer was born at Marbach, in Würtemberg, Feb. 17, 1723. His great fame rests on his lunar tables,

The angular distances of the moon from the sun, from four planets (Venus, Jupiter, Mars, and Saturn), and from nine stars (called lunar stars [1]), are given in the Nautical Almanac for the beginning of every third hour of mean time, for the meridian of Greenwich. The observer measures with a sextant the distance of the moon from one of these bodies, and after a long and intricate calculation (technically called "clearing the distance") he deduces the Greenwich time at the moment of observation. The observation of the moon's altitude, taken when the "distance" is measured, enables him to compute his own time; the difference between the two times is the longitude in time, as before.

You see what an amount of trouble is saved by having a chronometer. All the work in a "lunar" is in finding the Greenwich time corresponding to the "distance" we measure. We find the time between the three hours by proportional parts. When we have a chronometer we can note the Greenwich time at any instant.

which were published in 1753. These tables, which were compared by Bradley with the Greenwich Observations and found to be sufficiently accurate to determine the longitude at sea to within half a degree, solved the problem of practically determining longitude anywhere on the earth's surface."

Maskelyne (1732–1811) was the Astronomer-Royal at Greenwich for nearly half a century. The British Nautical Almanac was established by him in 1766.

[1] These stars are: Arietis, Aldebaran, Castor, Regulus, Spica, Antares, Formalhaut, Pegasi, and Aquilæ or Altair.

Chambers's Encyclopædia says :—

"This use of chronometers was first distinctly pointed out by Sir Isaac Newton. A committee of the House of Commons, of whom this philosopher formed one, having been appointed on the 11th June, 1714, to consider the question of encouragement for the invention of means for finding the longitude, the result of their meetings was a memorial containing an explanation of the different means proper for ascertaining the longitude, and recommending encouragement for the construction of *chronometers* as the best means of ascertaining it. An act of parliament was then passed, offering a reward for this purpose.

"The first chronometer used at sea was invented by John Harrison. After many years of study it was completed in 1736. After several further trials and improvements, and two trial voyages to America, undertaken for the satisfaction of the commissioners, the last of which was completed on the 18th September, 1764, the reward of £20,000 was finally awarded to Harrison."

The faith in chronometers[1] made its way slowly among seamen; even in the early part of the

[1] Even so late as 1844, Dr. Lardner said of chronometers :

"Although the art of constructing time-keepers has been brought to a high degree of perfection by the skill of modern artisans, these instruments are even yet, and probably will ever continue to be, too imperfect to be implicitly relied upon.

"In voyages or journeys which occupy months, we cannot rely on the indications of these instruments, even when most liberally provided or most perfectly constructed."

This reminds one of Dr. Johnson's sagacious remark, that England would never become a commercial country.

present century old navigators pinned their faith to the "lunar observation." They feared the chronometer would change its rate, or run down. Since about 1830, however, navigators have trusted to them implicitly. But as they are *liable* to accident, the Nautical Almanac continues to give the Greenwich time and lunar distances as before. Ships of war are usually provided with three chronometers; merchantmen with but one.

We see, then, our navigator on his voyage to Rio finds the position of his ship daily, and marks it upon his chart. After marking the chart, he shapes his course for the next twenty-four hours. The "chart" is provided by the Hydrographic Office, and is a delineation of the water and land between New York and Rio de Janeiro. As the seaman draws near his port, he consults a chart of the harbor to inform himself more particularly of the marks and bearings by which to enter it.

Should our navigator be in a sail-vessel, he stands from New York bound to Rio in a south-easterly direction, and may sight the Cape de Verde Islands. He soon gets the N. E. trades, and he then steers so as to cross the equator in about longitude 30°; so that when he gets the S. E. trades he may be in a position to weather Cape St. Roque, the eastern extremity of South America. By sighting the Cape de Verde Is-

lands, or any other land whose position is well established, the navigator is enabled to "verify" his chronometer.

The seaman watches the compass very closely. The variation of the compass differs in various latitudes and longitudes. It is easily found by celestial observations. By taking the altitude

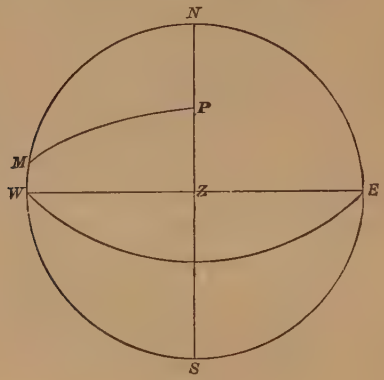

FIG. 17.

of the sun in the morning or evening we can calculate its *true* bearing; and if we observe the compass bearing at the same instant, the difference between them is the variation, provided there is no local attraction; but in any case it is the "error" of the compass, whether made up of the "variation" and "local attraction" combined, or not. This is called finding the *azimuth* of the sun, or its distance from the north

or south points. In the diagram (Fig. 16), page 236, the azimuth is the angle P Z M. To find it we have given the three sides, just as we had in computing the sun's hour angle.

Another method to determine the variation is to take the bearing of the sun at sunset or sunrise. We calculate its *true* bearing, and the difference is the variation. This is called finding the sun's *amplitude*, or distance from the east or west points.

Let the diagram (Fig. 17) be a projection of the celestial sphere on the plane of the horizon; N, S, the north and south points; E, W, the east and west points; Z is the zenith; P the elevated pole; and let M be any celestial body on the horizon. Its amplitude is W M.

The triangle P N M is right-angled at N. P N represents the latitude of the observer, and P M is the polar distance of the object. M N is equal to 90° *minus* the amplitude. To find it we have:

$$\text{cos. P M} = \text{cos. P N cos. M N},$$

or,

$$\text{sine dec.} = \text{cos. lat. cos. M N};$$

hence, cos. M N, or the sine of the amplitude, is equal to sec. latitude into the sine of the declination.

We see that the amplitude depends upon the declination of the object and the latitude of the observer. We can, then, assume all latitudes

from 0_0 to 90°, and all declinations between 0 and 23½°, and calculate the sun's bearing. A table of this kind is inserted in our books on navigation. So that all the seaman has to do is to observe the bearing of the sun at sunset or sunrise by compass. The table gives him the *true* bearing. The difference is the error of his compass.

The time of sunrise or sunset depends also upon the declination of the sun and the latitude of the observer. In the diagram (Fig. 17), the sun being on the horizon at M, the angle we wish to find is M P Z, or the sun's hour angle, or the apparent time of sunset. Since M P N is the supplement of M P Z, we readily see that, —

$$\cos. \text{ M P Z} = - \text{ tang. dec. tang. lat.}$$

We calculate a table of this kind, also. It contains the time of sunrise and sunset for all latitudes and declinations. The seaman enters it with his latitude and the sun's declination, and finds at a glance the time of sunrise and sunset. It is the apparent time, of course; but the navigator finds it convenient to keep apparent time when at sea; for, as he is continually changing his longitude, and consequently his time, he has to set his watch every day at noon.

We have seen the use of most of the instruments I have mentioned as being essential to the seaman, viz., the compass, sextant, chronometer, log and line, etc. The artificial horizon is intended to use on shore when we cannot see the natural horizon. It is simply a shallow, rectangular box, or trough, filled with mercury. The observer stands at a little distance from it, where he can see the reflected image of the celestial object. He then, with the sextant, brings the body down until it just touches the reflected object; and since the angle of incidence is equal to the angle of reflection, he thus measures *twice* the altitude of the body. One half of this is the altitude, from which he computes his local time. The chronometer time being noted at the moment of observation, he can find its error. For in this case, as the longitude of the port is *known*, we add[1] the *longitude in time* to the mean local time, and this gives us the Greenwich time. The difference between this true mean Greenwich time and the time shown by the chronometer is the *error of the chronometer*, fast or slow.

After an interval of ten days the operation is repeated, and the error of the chronometer is again found. The difference between the two errors, divided by ten, gives the daily *rate of the chronometer*, gaining or losing. It is hardly

[1] In east longitude we would subtract it.

necessary to say that a new error for the chronometer is found by the navigator at every port, and perhaps a new rate; but, as I have remarked, it does not matter how much it is, so long as *we know it.* The test of a good instrument is in the *uniformity* of its rate.

We often hear it asked how far a ship can be seen at sea. In this case it is the sphericity of the earth, alone, that limits vision. The higher the observer, the farther he can see. A very simple problem in practical astronomy enables us to calculate the distance corresponding to different heights, and tables are calculated and inserted in our books. Thus, a mountain 1,000 feet high can be seen 42 miles, a mountain one mile high can be seen 96 miles, and so on. Knowing the height of a mountain, we enter the table and find how far it can be seen; and *vice versa.*

An observer on the deck of a vessel, 20 feet above the sea, can perceive an object on the horizon six miles off; this is, in fact, the limit of his sensible horizon. If he were a hundred feet high, he would see 13 miles. If a sailor, then, 20 feet above the water, sees on the horizon the royals of a ship which are 100 feet above the sea, the distance is $6 + 13$, or 19 miles.

One other point, and I have done. The navigator can calculate the time of high water at the

port he is about to enter. At some places this is a matter of importance, — at Eastport, Maine, for example, where the tide rises and falls about 20 feet. A vessel anchoring there in 18 feet of water at high tide, would find herself high and dry at low water. The time of high water at any port is readily found when we know the age of the moon and the time of high water on full and change days at that port, or the "establishment" of the port, as it is called.

I hope I have given you at least an *idea* of the manner in which a seaman finds his way across the ocean. If you have followed me, you see that the *theory* of navigation is not difficult to understand. The *art* requires experience. But just as there are good lawyers and bad lawyers, good doctors and bad doctors, so are there good and bad navigators. And I will close these *talks* with the remark that, although we have special schools for the lawyer, the doctor, the merchant, the farmer, the army officer, and the navy officer, many of which are largely endowed by the general Government and the States, we have no such schools for the merchant seaman. The State of New York keeps up the training-ship St. Mary's, and the Government keeps several training-ships; but these are for apprentice boys for the navy only. So far as I know, it is only at a few private

schools in the large sea-ports that a MATE can learn anything of the art of navigation.

The merchant-officer is intrusted not only with the property, but the *lives of thousands of human beings;* and yet there is absolutely no college in this country where he can learn both the theory and practice of navigation. *Mirabile dictu!*

APPENDIX.

DEFINITIONS.

Aberration. A small apparent motion of the fixed stars occasioned by the progressive motion of light and the earth's annual motion in its orbit.

Aerolites. An aerolite is a meteorite composed of stone

Aerosiderites. An aerosiderite is a meteorite composed of iron.

Almanac. The Nautical Almanac is an almanac containing the positions of the sun, moon, planets, and stars, and is prepared especially for the use of seamen.

Altazimuth. An instrument for measuring altitudes and azimuths, as its name denotes.

Altitude. The angular height of a celestial body above the horizon. On land it is measured by altazimuths, meridian circles, and other instruments. At sea it is measured by the quadrant or sextant.

Amplitude. The angular distance of a heavenly body from the east or west points, measured on the horizon.

Angle. An angle is the amount of divergence of two right or curved lines.

Annular. Having the form of a ring. Applied to eclipses of the sun.

Anomalistic. The anomalistic month is the time in which the moon goes from apogee to apogee again, or from perigee to perigee again. The anomalistic

year is the interval between the earth's passage from aphelion to aphelion again, or from perihelion to perihelion again.

Anti-trades. This name is sometimes given to the southwest winds we find north of the Tropic of Cancer, and the northwest winds south of the Tropic of Capricorn, between the parallels of 30° and 45° or 50°.

Aphelion. The point in an orbit farthest from the sun.

Apogee. The point in the moon's orbit farthest from the earth.

Apsis, plural **Apsides.** The line of apsides is the line passing through the aphelion and perihelion points.

Arc, Diurnal. The path described by a heavenly body between rising and setting.

Aries, First point of. One of the points of intersection of the celestial equator and the ecliptic. Right ascension and celestial longitude are reckoned from this point.

Ascending Node. The point where the moon passes north of the ecliptic.

Ascension, Right. The angular distance of a heavenly body from the first point of Aries (or the vernal equinox), measured on the celestial equator towards the east. It is reckoned in hours from 0 to 24.

Asteroids. The small planets, over 280 in number, between Mars and Jupiter.

Astrolabe. A rude instrument used by the navigators of the 15th, 16th, and 17th centuries to measure the altitudes of the heavenly bodies.

Astronomy. The law of the stars.

Axis. The line on which a body rotates.

Azimuth. The angular distance of a celestial body from the north or south points, measured on the horizon.

Base-Line. A measured distance on which to found a system of triangulation.

Bode's Law. Explained in the text.

Calendar. A method of reckoning time.

Catalogue-Star. A list of stars giving their names, magnitudes, right ascensions, and declinations.

Celestial. Appertaining to the heavens. Thus, we have the terrestrial meridian and the celestial meridian; the terrestrial equator and the celestial equator; the terrestrial poles and the celestial poles; the one being the prolongation of the other to the heavenly sphere.

Centrifugal Force. The force which gives a body moving round another body a tendency to move off at a tangent to the periphery of the curve.

Centripetal Force. The force holding a body towards the centre; such as the attraction of the sun.

Circumpolar. Round or near the pole. Applied to the stars which do not set.

Clepsydra. A water-clock.

Co-latitude. The latitude of a place subtracted from 90°. The *complement* of the latitude.

Colures. The celestial meridians passing through the equinoxes and solstitial points, called the equinoctial and solstitial colures.

Complement. What an arc or angle wants of 90°.

Conjunction. Seen in the same direction. Celestial bodies are in conjunction when they have the same longitude.

Constellation. A group of stars supposed to represent some figure.

Culmination. The passage of a heavenly body across the meridian of the observer. A transit.

Cycle. A period of time, such as a lunar cycle; the cycle of eclipses, called by the Chaldeans *Saros*.

Day. When we speak of a day in astronomy, we mean a solar day of twenty-four hours, unless we specify a lunar day or a sidereal day.

Declination. The angular distance of a heavenly body north or south of the celestial equator. The complement of the declination is the polar distance.

Degree. The 360th part of a circle, marked thus, °.

Density. Compactness; comparative weight.

Descending Node. The point where the moon passes south of the ecliptic.

Diameter. A right line, which, passing through the centre of a circle or sphere, divides it into two equal parts.

Digit. In astronomy, the twelfth part of the diameter of the sun or moon, used in measuring the extent of a partial eclipse.

Dip. The dip of the horizon is the depression of the sensible horizon below the celestial or true horizon.

Disk. The visible surface of the sun, moon, or planets.

Eccentricity. The eccentricity of an ellipse is the distance of either focus from the centre, divided by half the major axis.

Eclipse. Literally, a disappearance; caused by a body entering into the shadow of another.

Ecliptic. The great circle (or more properly *ellipse*) of the heavens along which the sun *appears* to perform his annual journey.

Elements. Chemical elements refer to the substances found in the sun and stars, etc. The elements of the orbits of the planets are the distances from the sun, times of rotation, diameters, masses, etc. Elements of position are, right ascension and declination, latitude and longitude, altitude and azimuth, etc.

Ellipse. An oval figure, an oblique section of a cone.

Elongation. The angular distance of a planet from the sun.

Ephemeris. An account of the daily motions and positions of the celestial bodies; an almanac.

Equator. The terrestrial equator is an imaginary circle, running round the earth half-way between the poles. It is called the *equator* because when the sun is on it the days and nights are of equal length. It is also called the equinoctial line. The plane of the equator produced to the heavens marks the celestial equator, or equinoctial.

Equinoxes. The points of intersection of the ecliptic and the equator are called the vernal and autumnal equinoxes.

Establishment. The interval at new or full moon between the time of the moon's meridian passage and high water is called the "establishment of the port."

Evening Star. Venus, when visible in the evening after sunset, is called the evening star. The ancients called it Hesperus, or Vesper.

Faculæ. The brightest parts of the solar photosphere are called faculæ.

Focus. The point of convergence, where the rays of light are concentrated by a lens or burning-glass; plural, *foci*.

Galaxy. The Greek name for the Milky Way, or *Via Lactea*.

Geocentric. Viewed from the centre of the earth.

Gibbous. Applied to the appearance of the moon between its first quarter and full moon, and between full moon and third, or last quarter.

Gnomon. The hand of a dial; also in ancient times an instrument for measuring altitudes; used by the Greeks for determining the sun's altitude as far back as 276 B. C.

Gravity. Tendency to the centre; weight. The *specific gravity* is the weight of the matter of any body, compared with the weight of an equal bulk of pure water, taken as a standard.

Great Bear. The constellation *Ursa Major*, called also, the "Dipper," "Charles' Wain," the "Seven Stars," the "Wagon."

Harvest Moon. The moon in harvest-time (in England), near the autumnal equinox, when it rises near the same hour for several successive evenings. This occurs, usually, at the times of two full moons, one in September and the other in October. The first is called the *harvest moon*, the second the *hunter's moon*.

Heliocentric. Viewed from the centre of the sun; as opposed to geocentric.

Hemisphere. If a plane be passed through the centre of the earth, at right angles to its axis, it divides the earth into the north and south hemispheres. A half sphere.

Horizon. The line where the heavens and earth seem to meet is called the *visible* or *sensible horizon*. The *rational* or *true horizon* is a great circle of the heavens, the plane of which is parallel to the plane of the visible horizon, but which, instead of being a tangent to the earth's surface, passes through its centre.

Horizontal Parallax. Explained in text.

Hour-angle. The angular distance of a heavenly body from the meridian.

Hour-circle. The circle attached to the equatorial instrument, by which right ascensions are indicated.

Hyperbola. One of the conic sections.

Inclination. The inclination of an orbit is the angle between the plane of the orbit and the plane of the ecliptic. We have also the "inclination" of the earth's axis, the planets' axes, etc.

Inferior Conjunction. When an inferior planet is in a line between the earth and sun, it is said to be in *inferior conjunction* with the sun.

Inferior Planets. The planets Mercury and Venus are called *inferior planets*, because their orbits are *within* the orbit of the earth.

Irradiation. A bright object makes a stronger impression on the eye than a dim one, and appears larger the brighter it is, — this is called *irradiation*.

Julian Calendar. The calendar as corrected by Julius Cæsar.

Latitude. Terrestrial latitude is the angular distance of a place, north or south of the equator. It is measured on a meridian. *Celestial latitude* is the angular distance of a heavenly body from the plane of the ecliptic.

Limb. The edge of the disk of the sun, moon, or planet.

Longitude. Terrestrial longitude is the angular distance of a place, east or west of the meridian of Greenwich. It is measured on the equator. *Celestial longitude* is the angular distance of a heavenly body from the first point of Aries. It is measured on the ecliptic, and is reckoned up to 360°.

Lunation. The period of the moon's journey round the earth.

Mass. The quantity of matter a body contains.

Meridian. The great circle of the heavens passing through the zenith of any place and the poles of the celestial sphere.

Micrometer. An instrument for measuring small angular distances.

Nadir. The point beneath the feet.

Neap. Twice in every lunar month the tides are lower than usual, this occurs about a day or two after the moon is in her quadratures. These are called neap tides.

Nebula. A name given to faint, misty appearances, which are dimly seen among the stars, resembling a comet.

Nodes. The points at which a comet's or planet's orbit intersects the plane of the ecliptic; one is termed the ascending, the other the descending node.

Nutation. An oscillatory movement of the earth's axis due to the moon's attraction on the equatorial protuberance.

Oblate. An oblate spheroid is a solid generated by the revolution of an ellipse about its minor axis. The equatorial diameter is, then, greater than the polar diameter.

Obliquity (The) of the ecliptic is the angle the plane of the ecliptic makes with the plane of the celestial equator.

Occultation. The eclipsing of a star or planet by the moon or a planet.

Opposition. A superior planet is in opposition when the sun, earth, and the planet are in the same straight line, with the earth in the middle.

Orbit. The path of a planet or comet round the sun, or of a satellite round a primary.

Parallax. The difference between the true and the apparent direction of a celestial body, owing to a change in the place of the observer.

Parallels. Imaginary small circles on the earth's surface, parallel to the equator, are called parallels of latitude.

Penumbra. The half-shadow which surrounds the deeper shadow in an eclipse.

Perigee. The point in the moon's orbit nearest the earth.

Perihelion. The point in an orbit nearest the sun.

Period. The *period*, or *periodic time*, of a heavenly body is the *exact* time it takes to complete one revolution about the sun. A *synodic period* is the time in which a planet returns to the same position *with regard to the sun and earth*.

Perturbations. The effects of the attractions of the planets and satellites upon each other, consisting of variations in their motions and orbits.

Phases. The various appearances presented by the illuminated portions of the moon and inferior planets in different parts of their orbits.

Photosphere. The exterior surface presented by a star, or the sun.

Plane. A plane is a surface with which a straight line that joins any two of its points will coincide altogether.

Polar. The line through the earth's centre from pole to pole, is called the Polar Diameter. *Polar distance* is the angular distance of a celestial body from the celestial poles. It is the *complement* of the declination, or 90° minus the declination.

Polaris. The pole-star, called also the north-star.

Poles. The extremities of the imaginary axis on which a celestial body rotates. The *poles of the heavens* are the extremities of the axis of the celestial sphere.

Precession. The precession of the equinoxes is a slow but continual shifting of the equinoctial points from east to west. The amount of precession annually is $50\frac{1}{10}$ seconds ; hence it appears that the equinoctial points will make an entire revolution in 25,868 years.

The Prime Vertical. The prime vertical circle is a great circle of the celestial sphere passing through the east and west points, and through the zenith, of course.

Quadrant. An instrument used by seamen to measure the altitudes of the heavenly bodies; but *sextants* are now almost universally used.

Quadrature. Two heavenly bodies are said to be in quadrature when there is a difference of longitude of 90° between them.

Refraction. In astronomy, deviation of a ray of light, owing to its passing through the earth's atmosphere.

Rotation. The motion of a body round a central axis. Thus the daily turning of the earth on its axis is a *rotation;* its annual motion round the sun is a *revolution.*

Saros. A term applied by the Chaldeans to the cycle of eclipses.

Satellites. The smaller bodies revolving about planets.

Scintillation. The "twinkling" of the stars.

Selenography. A description of the moon.

Sextant. An instrument used by seamen for measuring the altitudes of, and angular distances between, the heavenly bodies; also used in hydrographic surveying.

Shooting-Stars. A name applied to meteors.

Sidereal. Relating to the stars.

Signs of the Zodiac. The celestial equator is divided into 12 signs of 30° each, and thus called.

Solstices. The points in the sun's path at which the extreme north and south declinations are reached, and at which the motion is apparently arrested before its direction is changed. June 21 is called the summer solstice, and December 21 the winter solstice.

Spectroscope. An instrument used for the examination of the *spectra* of the heavenly bodies.

Spectrum. The luminous colored band produced by the dispersion of light.

Spring. The spring tides are the two highest tides that occur in a lunar month, a day or two after new and full moon.

Superior Conjunction. When an inferior planet is in a line with the sun, but beyond it, it is said to be in superior conjunction.

Synodic Period. In consequence of the earth's motion, the period in which a planet regains the same position with regard to the earth and sun is different from the actual period of the planet's revolution round the sun. The time in which a position, such as conjunction or opposition, is regained, is called a synodic period. Thus, a lunar month is a synodic period.

Syzygies. The two points in the moon's orbit corresponding to new and full moon.

Terminator. The boundary between the bright and shaded portions of the moon is thus called.

Transit. The passage of a heavenly body across the meridian of a place. A culmination. Also, the passage of a heavenly body across the disk of another; such as a transit of Venus.

Tropics. The circles of declination (of the celestial sphere) which mark the most northerly and southerly points in the ecliptic, in which the sun occupies the signs, Cancer and Capricorn, respectively. On the earth, a name given to two parallels of latitude, one (the tropic of Cancer) being 23° 28′ north of the equator, and the other (the tropic of Capricorn) being 23° 28′ south of the equator.

Umbra. The darkest central portion of the shadow cast by a heavenly body in an eclipse.

Universe. The whole creation, including the solar system, and all the starry regions beyond.

Vertical. Placed or being in the zenith, or perpendicularly overhead. A vertical circle is one that passes through the zenith and nadir of the celestial sphere; it is perpendicular, of course, to the horizon. Altitudes are measured on vertical circles.

Via Lactea. The Milky Way.

Volume. The cubical contents of a body.

Zenith. The point of the celestial sphere overhead.

Zodiac. A portion of the heavens extending 9° on either side of the ecliptic, in which the sun and major planets appear to perform their annual revolutions.

Zodiacal Light. A faint light, somewhat like the Milky Way, seen in the west shortly after sunset in winter and spring. Its origin is unknown, though there are many speculations concerning it.

Zone. One of the five divisions of the earth's surface formed by means of the two tropics, and the two polar circles.

INDEX.

Aberration of light, 140.
Absolute time, 181.
Almagest, 27.
Almanac, nautical, 239.
Alpha Centauri, parallax of, 154.
Altazimuth, 201.
Altitude, 218.
Amplitude, 241.
Angular diameter of sun, 44.
Annular eclipse of sun, 107.
Antarctic Circle, 40.
Aphelion, 169.
Apogee, 77.
Apparent motion of sun, 42.
Apparent solar day, 170.
Apparent time, 170.
Apsides, 180.
Arctic Circle, 40.
Argelander, 151.
Aristarchus, 27, 39.
Artificial horizon, 243.
Asteroids, 137.
Asteroids, force of gravity on, 138.
Astrolabe, 207.
Astronomical day, 172.
Astronomers, first, or early, 21.
Astronomy defined, 17.
Astronomy, nautical, 198.
Autumn, length of, 48.
Azimuth, 240.

Bessel, 153.
Bishop Wilkins, 116.
Bode's Law, 132.
Bradley, discoverer of aberration of light, 141.

Cæsar, Julius, 24.
Calendar, 24.
Calendar, Gregorian, 26.
Calendar, Julian, 25.
Carlyle, 16.
Cassini, 36.
Cavendish experiment, 144.
Chaldeans, 26.
Charles's Wain, 165.
Chart, 239.
Chronometer, 232.
Chronometers, introduction of, 236.
Chronometer, verifying, 240.
Civil day, 172.
Clepsydræ, 174.
Climate of southern hemisphere, 45.
Clocks, 176.
Columbus, 29.
Columbus, voyage of, 206.

Comets, 161, 163.
Compass, error of, 240.
Compass, mariner's, 204.
Compass, variation of, 214.
Condamine, 36.
Constellations, 155.
Constellations, zodiacal, 158.
Copernicus, 28, 207.
Crepusculum, 53.
Cycle, lunar, 89.
Cycle, metonic, 89.
Cycle of eclipses, 110.

Day, 23.
Day, apparent, 170.
Day, mean, 170.
Day, sidereal, 170, 173.
Days, long and short, 49.
Days of week, 177.
Day, universal, 188.
Dead reckoning, 228.
Density of earth, calculation of, 143.
Densities of sun and planets, 147.
Departure, 226.
Difference of latitude, 228.
Difference of longitude, 228.
Dip of the horizon, 220.
Dipper, 156, 165.
Distance of an object at sea, 244.
Dropping a day, 192.

Earth, 30.
Earth, axis of, 40.
Earth, density of, 143.
Earth's density calculated, 143.
Earth's meridian measured, 34.
Earth-shine, 76.
Eclipse, moon, 108.
Eclipse, sun, 106.
Eclipses, 105.
Eclipses, number of in any one year, 109.
Ecliptic, 40.
Ecliptic, obliquity of, 39.
Egyptians, 26.
Elements in sun and stars, 101.
Ephemeris, nautical, 201.
Equation of time, 171.
Equator, an observer at, 62.
Equatorial instrument, 201.
Equinoxes, 41.
Equinoxes, precession of, 159, 166.
Eratosthenes, 32.
Error and rate of the chronometer, 243.
Establishment of the port, 245.

First meridian, 187.
Flavio Gioja, 204.
Foucault's experiment, 30.

Galaxy, 160.
Galileo, 28.
Geography of the heavens, 157.
Gioja, Flavio, 204.
Glasses, hour, 210.
Globes, use of, 157.
Gnomon, 33.
Golden number, 89.
Greenwich meridian, 189.
Gregorian calendar, 26.

Heat of sun, 110.
Heat received from moon, 84.
High water, 90.
High water, head of, 91.
High water, time of, 245.
Hipparchus, 27.
Hour-glass, 210.
Hour, universal, 188.

Horizon, 252.
Horizon, artificial, 243.
Horse latitudes, 213.
Hutton, 146.

Inclination of moon's orbit, 85.
Index correction, 219.
Initial point of day, 182.
International conference, 187.
Introduction of chronometers, 238.

Julian calendar, 25.
Jupiter, description of, 129.
Jupiter, satellites of, 105, 133.
Jupiter, seasons of, 139.

Kepler, 28.
Kepler's laws, 141.

Landfall of Columbus, 215.
Latitude, 228.
Librations, 77.
Light, aberration of, 140.
Light shed by moon, 84.
Light, velocity of, 134.
Local time, 181.
Lode star, 203.
Lodestone, 202.
Log and line, 211, 226.
Longitude and time, 181.
Longitude by chronometer, 233.
Longitude by lunar observation, 236.
Lunar cycle, 89.
Lunar day, 172.
Lunar eclipse, 108.
Lunar stars, 237.

Magellan, 161, 195.
Magellanic clouds, 161.
Magnetic needle, 203.
Marco Polo, 203.
Mariner's compass, 204.
Mars, calculation of distance of, 97.
Mars, description of, 127.
Mars, discovery of satellites of, 115.
Maskelyne, 144.
Mason and Dixon's line, 37.
Mean day, 170.
Mean time, 170.
Mercury, climate of, 139.
Mercury, description of, 118.
Meridian circle, 200.
Meridian, earth's measurement of, 34.
Meridian, first, 188.
Meridian, Greenwich, 189.
Meridian, neutral, 191.
Meridian, 180th, 195.
Meridian, prime, 187.
Meteors, 161.
Meteorites, 162.
Midnight sun, 54.
Milky way, 160.
Moon, attraction of gravitation at surface, 92.
Moon, light shed by, 84.
Moon, phases of, 66.
Moon, rule for finding age of, 72.
Moon, the, 63.
Moon's angular diameter, 78.
Moon's diameter, calculation of, 83.
Moon's distance from the earth calculated, 78.
Moon's heat, 84.
Moon's horizontal parallax, 79.
Moon's influence, 90.
Moon's nodes, 85.

Moon's orbit, inclination of, 85.
Moon's revolution upon its axis, 77.
Moon's rising, errors about, 73.
Moon's surface, 85.
Moon's volume, calculation of, 83.
Month, 24, 178.
Month, anomalistic, 178.
Month, calendar, 178.
Month, lunar, 76, 178.
Month, nodical, 178.
Month, sidereal, 76, 178.
Month, synodic, 76.
Month, tropical, 178.

Nautical Almanac, 202, 239.
Nautical astronomy, 198.
Nebulæ, 160.
Nebular hypothesis, 160.
Needle, magnetic, 203.
Neptune, description of, 131.
Neptune, discovery of, 114.
Neutral meridian, 191.
Newton, Isaac, 28.
Nodes, 85.
North pole, an observer at, 59.
North star, 156.
Nutation, 167.

Obliquity of the ecliptic, 40.
Observers, early, 21.
Occultations, 105.
Occultations of Jupiter's satellites, 106, 133.
Octants, 68.

Parallax, 218, 224.
Partial eclipse of sun, 107.
Perigee, 77.
Perihelion, 169.
Phases of moon, 66.
Photosphere, sun's, 101.
Picart, 36.
Planets, 112.
Planets, density of, 146.
Planets, inhabited, 138.
Planets known to the ancients, 113.
Planets, masses of, 142.
Planets, satellites of, 114.
Pleiades, 165.
Pope Gregory XIII., 25.
Precession of the equinoxes, 159.
Prime meridian, 187.
Ptolemy, 27.
Pythagoras, 27.

Quadratures, 68.

Radius, vector, 141.
Refraction, 218, 221.
Relative time, 181.
Repeating a day, 193.
Reverse bearing, 226.
Roemer, 134.
Roger Bacon, 203.
Rousseau, 17.
Royal Society of England, 116.
Rule for finding moon's age, 72.
Running time, 185.

Sargasso Sea, 214.
Saros, 110.
Saturn, description of, 130.
Schehallien, 145.
Seasons, change of, 39.
Secondary light, 76.
Semi-diameter, 218.
Seven stars, 165.
Sextant, 218.
Shooting stars, 161.
Sidereal day, 170, 173.
Sidereal time, 173.

Solar eclipse, 106.
Solar system, 113.
Solstices, 40.
Sound, rate of travel, 135.
Southern hemisphere, climate of, 44.
Specific gravity of the earth, 143.
Spectroscope, 101.
Spectrum analysis, 101.
Spring, length of, 48.
Standard time, 183–185.
Star-clusters, 160.
Star-showers, 161.
Stars, 149.
Stars, circumpolar, 174.
Stars, classification of, 159.
Stars, distance of, 150.
Stars, double, 160.
Stars, greatest number seen, 59.
Stars, least number seen, 59.
Stars, magnitudes, 151.
Stars mentioned in Bible, 159.
Stars, names of, 151.
Stars, number of, 150.
Stars, variable, 160.
Summer, length of, 48.
Sun, angular diameter of, 44.
Sun, apparent motion of, 42.
Sun, description of, 93.
Sun-dial, 174–176.
Sun, diameter in miles, 95.
Sun, heat of, 110.
Sun, if inhabited, 99.
Sun, midnight, 54.
Sun's distance, how found, 94.
Sun's hour angle, 171.
Sun's influence, 110.
Sun's parallax, how calculated, 95.
Sun's photosphere, 101.
Sun's rising point, 101.
Surface of moon, 88.
Syzygies, 68.

Telescope, 199.
Telescope, first used, 134.
Terminology, 18.
Tides, 90.
Time, measurement of, 168.
Time, natural standard of, 168.
Time of sunrise, 175.
Time, standard, 183.
Time, standard of, 24, 168.
Trade winds, 212.
Transit instrument, 199.
Transit of Venus, 94.
Tropics, 40.
Twilight, calculation of, 52.

Ulloa, 37.
Universal day, 188.
Universal hour, 187.
Uranus, description of, 130.
Uranus, discovery of, 114.
Ursa, Major, 156.

Variation of the compass, 214.
Velocity of earth in its orbit, 63.
Velocity of earth round its axis, 63.
Velocity of light, 134.
Velocity of light, how discovered, 135.
Venus, description of, 122.
Venus, distance from earth calculated, 126.
Venus, transits of, 94, 96.
Verifying the chronometer, 240.
Voyage of Columbus, 206.
Voyages, Arctic, 57.
Voyages, Chinese, 202.
Voyages, Phœnicians, 202.

Wagon, 166.
Wane, 71.
Wax, 71.
Week, 177.
Week, days of, 177.
Winter, length of, 48.

Year, 24, 178.
Year, anomalistic, 179.
Year, sidereal, 179.
Year, tropical, 179.

Zenith, sector, 201.
Zodiac, 158.
Zodiac, signs of, 159.
Zodiacal constellations, 158.
Zones, 40, 47.